STANDARD TESTING
OF
ELECTRICAL APPARATUS

No. 2170

Instructions

for

Testing Electrical Apparatus

GENERAL INSTRUCTIONS FOR TESTING

Introduction

This book is intended to give a general outline of the methods and precautions to be followed in test. Every one making tests must become familiar with its contents, and will be held responsible for carrying out tests in accordance with the methods and regulations outlined. If, after reading the description of any test, the tester is doubtful about specific points, he should refer the matter to the Head, or Assistant Head of the Section for further instructions before undertaking the work.

Instructions regarding wiring, starting, and operating machines as given in this book must be followed out carefully and conscientiously, and under no circumstances will deviations be allowed unless permission has been first received from those in authority. The importance of carefulness must be realized at the outset, since practically all accidents likely to happen to men or apparatus are due to carelessness or lack of appreciation of operating conditions. The Company does not hold itself responsible for such accidents, and any man doing careless work, or taking any risks that may have serious results, renders himself liable to discharge. No one must handle any wiring, connect or operate any switchboard or apparatus unless he is entirely familiar with all the conditions having reference to the test. In addition to being thoroughly familiar with the contents of this book, every one is expected to keep himself informed regarding instructions that are issued from time to time by the Heads of the Testing Department. Such instructions are posted, when issued, on the various section and general bulletin boards provided for that purpose.

TESTING EQUIPMENT

Electrical Power

In order to test apparatus under operating conditions it is necessary to provide power at various voltages and frequencies so that either direct current or alternating current apparatus may be readily operated. Direct current power in the Testing Department is obtained either direct from the steam plants in the works located in Building No. 13 and Building No. 61, or from synchronous motor generator sets installed in the various testing sections, the motors of which operate from the 40 cycle alternating current shop system. The regular direct current shop circuits furnish power at 125 volts, 250 volts and 500 volts. By using other shop generator sets connected in series with the above circuits, intermediate and higher direct current voltages may be obtained where testing conditions so require. These shop generators are commonly known in the Testing Department as "boosters" or "exciters." These generators alone may be used for furnishing small and moderate amounts of power at variable voltages and where close and variable voltage control is required. The regular shop circuits carry a fluctuating factory and railway load and, therefore, cannot be relied upon to give close voltage regulation. The latter must be used, however, wherever large amounts of power are required, in which case the voltage regulation must be effected by means of shunt boosters in series, the fields being controlled so as to maintain the proper terminal voltage.

Direct current power at 1200 volts is used chiefly for the testing of high voltage direct current railway motors, and is obtained by boosting the 500 volt shop circuit by an auxiliary generator. In all cases where it is not necessary to have one side of the 1200 volt circuit grounded it should be so wired that there will not be more than 600 volts between either side of the circuit and ground, since the 500 volt shop circuit is permanently grounded on one side, this condition can be readily obtained by connecting the boosting generator to the grounded side of the shop circuit. It must be understood in this connection that, in all testing work, no ground is to be used as a return circuit; that is, all circuits must be metallic. The 250 volt shop circuit has a grounded neutral; the 125 volt shop circuit is obtained between either side of the 250 volt circuit and the grounded neutral. All direct current shop circuits are wired through circuit breakers and switches permanently mounted on switchboards in each testing section. These circuit breakers and switches control the whole power in their section; they must, therefore, all be opened whenever power is no longer required.

Each of the principal testing sections is equipped with a number of small direct current generators capable of giving a variable voltage for testing work which are known as "exciters," because they are used frequently for field excitation. These generators are direct motor driven, steam turbine driven;

engine driven, or belted sets. Turbine driven sets consist of a Curtis Turbine driving one or two generators. When the turbine drives two generators, the switchboard is arranged so that the two armatures can be connected in series or multiple. Belted sets are considered as temporary testing sets and are only used in emergency, since their use requires greater care and attention. Their operation is also a possible source of danger, in consequence of the possibility of slipping or breaking belts, etc.

When an exciter runs in series with a power circuit in order to "boost" or "buck" the voltage the following points require careful consideration. Under no circumstances must the source of driving power be disconnected while the exciter carries load. Therefore, no machine must ever be used in such cases unless it is equipped with a speed limiting device in good working order, which will automatically open the circuit breaker of its armature circuit, should the machine begin to operate at excessive speed. Particular care should always be taken to see that all safety devices, in operation with such machines, are in good working condition before using them. All permanently installed motor-generator sets have a speed limiting device and low voltage release installed on the motors and generators. These are wired in series, so that in case the speed rises suddenly, both motor and generator circuit breakers will be automatically opened and the set shut down. For the same reason, if the power supply from which the sets are driven fails all breakers will be opened automatically. On direct current turbine driven sets the circuit breaker tripping coils are wired so that, when the emergency governor operates, their circuits are broken and the breakers in the generator armature circuit are opened.

All speed limiting devices on shop apparatus are adjusted to operate at 10 per cent. above normal speed. All such devices must be tested regularly at least once each week. The head of the testing section must see that this is done. Turbine driven generators should not be used to "buck" the shop voltage, since engine driven and turbine driven sets rely only on their friction and windage losses to prevent their speed from increasing when the direct current generator is "motoring"

Measurement of ohmic resistance is one of the most common tests and it frequently requires much skill to obtain consistent results. The Testing Department is equipped with special measuring booths located in the various testing sections, fitted with measuring sets provided with d'Arsonval galvanometers. The resistance bridges and resistances used are especially adapted to the work. The measuring sets are supplied with storage batteries to furnish current for making the measurements. Care must be taken when charging the batteries to see that they are not charged at too great a rate, also that a high discharge rate does not last for too long a period. Occasionally the battery acid should be tested to see that it maintains the proper specific gravity. This test is made by a hydrometer.

In order to prevent vibration, the galvanometers are carried on piers, having no connection with the building foundations.

It is essential that the galvanometers are carefully protected from vibration or shock, otherwise, resistance measurements cannot give accurate results.

The Testing Department has alternating current generators and motor-generator sets for generating and converting alternating current power at the various voltages and frequencies required in testing apparatus. Taps, from the 40 cycle alternating current shop circuit supplying 110 volts, are located in the principal testing sections. These are generally used for supplying power for the excitation of high potential testing transformer sets. As this power is supplied at a constant voltage of 110 volts, a potential regulator is employed with the high potential testing transformer, in order to obtain the high potentials necessary for the various types of apparatus tested. The wiring arrangement of a high potential testing set is shown in Fig. 1.
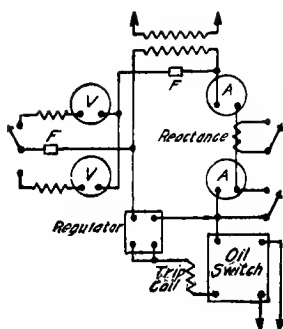

Fig. 1
WIRING ARRANGEMENT OF HIGH POTENTIAL TESTING SET

The Testing Department uses a 2000 Kw. 25 cycle, 13,200 volt turbine driven generating set located in Building No. 61 for miscellaneous power tests. From this set power is distributed by means of high tension lines to Buildings Nos. 16, 12 and 114. This set is also used for supplying power to the railway at Wyatts Crossing and a considerable amount of railway testing is done by its agency. When such work is being carried on, an extensive system of high tension lines is connected to this machine, consequently the circuit has considerable capacity. When this circuit is in use, therefore, testers should be cautioned not to come in contact with any part of the circuit, or with the leads attached to it, since its capacity may give rise to a voltage sufficient to produce fatal results. No one working on this circuit, or other circuits of high voltage in the Testing Department, should approach nearer than 12 inches to the circuit, because actual contact is by no means

always necessary in order to receive a dangerous shock. Due to high static capacity and other peculiar conditions, it is extremely important that the head of the section investigate thoroughly other sections which have taps to these lines and make sure that they are not, and will not be in use, before anyone is allowed to operate this machine. This must be done in order that all taps may be properly protected when not in use, and also that no accidents may occur, due to misunderstandings. No wiring whatever should be done on this circuit while it is alive. In all
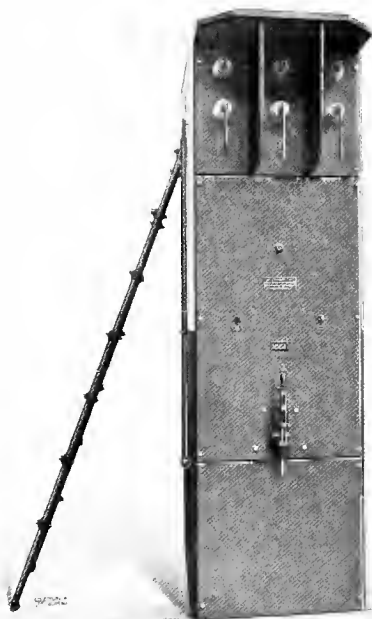
Fig. 2
FRONT OF HIGH TENSION FLOOR PANEL

cases, tests being operated from this circuit must have oil switches interposed between the test wiring and the lines so that connections to the lines may be made through these switches. Wherever temporary switches become necessary they must either be located at such a height or be protected by a mechanical barrier so that men cannot accidentally come in contact with them. Oil switches, permanently installed in the different testing sections for connecting to the lines mentioned

above, must be kept locked open when power is not being drawn from the lines. The head of the section is responsible for seeing that these matters are attended to.

The Testing Department motor-generator sets, with the exception of those already mentioned, may be operated for the conversion of direct to alternating current or vice versa. The armature terminals of all alternating current generators are connected to high tension switch panels. By this means, the
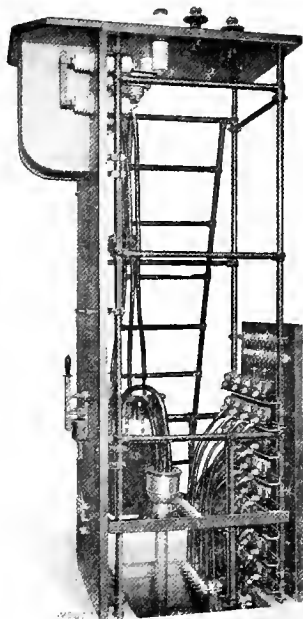
Fig. 3
HIGH POTENTIAL FLOOR STAND SHOWING
INTERIOR WIRING AND CONSTRUCTION

armatures, when their windings permit, may be readily connected Y or △ three-phase, or two-phase. Although such switch-board panels are insulated for 15,000 volts, the same caution, nevertheless, should be observed in operating them as though the lines were bare conductors. The armature coil terminals are each marked on the terminal board. One of the panels is shown in Figs. 2 and 3. When three-phase Y is desired, plugs are placed in the terminals marked Y, whereas if three-phase

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delta is required, plugs are used at the terminals marked delta. Terminals marked L-1, L-2 and L-3 are connected to the high potential transfer switchboard.

Steam Power

A considerable amount of steam is used for the testing of steam turbines, marine engines and for driving turbine and engine driven exciter sets, steam pumps, etc. Steam is supplied to the Testing Department from power houses located in Buildings Nos. 13 and 61 and is conveyed to the Testing Department through underground mains in the yards. The steam pipes are placed overhead in all buildings. These mains are well lagged with asbestos covering and contain a sufficient number of expansion joints to take care of all expansion and contraction. Gate valves are located in the mains at the boiler houses and also just inside the buildings in which the testing section is located. Motor operated emergency valves are installed in the important mains, so that the steam supply may be shut off by closing a switch in the testing section. Each man working in the steam test should know where these switches are located, so that he may be able to close these valves quickly if necessity arises. These valves must be regularly tested at least once a week to insure certain operation. Steam separators and traps are connected in all mains at the proper points to take care of condensed water. Steam is distributed from the mains to the various section testing stands by leading off pipe branches. These branches are of sufficient size to test any machine that will be placed in the particular testing stand. At each stand the branch steam mains are fitted with two steam valves, viz: a special Globe Valve, which may be used to throttle steam for machines under test, when necessary, and another valve which is never to be used for throttling. This arrangement prevents any steam leaking through the branch when not in use. Each valve is furnished with a handwheel of sufficient diameter, so that no additional leverage should be necessary in opening or closing.

All steam valves must be tightly closed, using the handwheel fitted to the valve, the handwheel should then be given a slight backward turn in order to free the stem sufficiently to take care of expansion and contraction. If these precautions are observed the valve may always be easily operated by the handwheel. Each branch main valve is furnished with a small by-pass valve. When it is possible to obtain a sufficient supply of steam through these by-pass valves to operate a test, they should be used in preference to throttling with the large valve. Drip cocks are in all cases located between the main valve and the machine or throttle valve. These drip cocks must always be open when steam is not flowing through the main in which it is located, and should be left open until steam is flowing freely through the main. That is, wherever condensed water can collect in dead end mains, a drip should be provided to carry this water away as fast as it collects, in order to prevent a

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water hammer in the main. A water hammer may produce enormous stresses in a steam main, hence, great care must be taken to prevent its development. If water is likely to collect in the main, the supply of steam should be entirely shut off and all water must then be removed before re-opening the steam valve and attempting to use the main again.

In each section having large steam mains, regularly appointed men are located, whose duty it is to operate all valves with the exception of the throttle valve at the machine under test. The tester should, therefore, ask these men to operate any valve except the throttle valve, which may be operated by the tester himself. Small by-pass valves should also be used in every case to gradually warm up a steam main before allowing steam to flow into it through the opening of the main valve. By using the by-pass valve in this manner, with all drips open, the main can be gradually brought to its running temperature, after which the large valve giving the full flow of steam may be opened.

All exhaust steam piping is arranged to permit the exhaust steam being passed into the heating system of the factory, into the atmosphere direct, or into surface condensers. Wherever possible, condensers should be employed in order to economize steam. Whenever steam heat is required, however, exhaust steam may be passed into the heating system. Steam should only be exhausted into the atmosphere direct in exceptional cases where it cannot be utilized as just mentioned.

Shop Motors and Generators

The Testing Department equipment includes a large number of 125, 250, and 500 volt direct current machines of various sizes, which are always available for driving generators under test. They can also be used as a load for motors receiving test, in which case they are run as generators. Many of these machines are shunt wound; a large number, however, are provided with a series field winding. Some of the larger sizes are also equipped with commutating poles. Ordinarily when using such machines as motors, they are operated as shunt machines. Sometimes, however, these motors have to operate in multiple, it is then necessary to use a certain proportion of the series field on one machine in order to give the proper speed equalization. Such cases, however, are special and definite instructions should be obtained before operating the combination.

When operating as motors machines should never be separately excited, unless the test requirements so demand. In such cases, precautions must be taken to prevent loss of motor field, due to the fields being excited from one source and the armatures from another. When shop machines are operated as motors they must have the speed limiting switch mounted on the shaft, connected to the trip coils on the breakers placed in the armature circuit, so that in case a motor begins to run too fast it will be automatically shut down.

When using direct current machines as compound wound motors, which is necessary when running the motors in multiple,

the following precautions must be observed. The series fields must not be connected differentially. They must have only sufficient series field to give the required regulation. Should excessive series field be used and the shunt field adjusted under full load conditions to give normal speed at normal load, the speed may rise to a dangerous point if the load falls suddenly. When machines are so used or when they are being used as "boosters", great care should be exercised in operation to prevent any condition occurring which may give a dangerous rise in speed. When such special conditions occur in test it must be clearly understood that some one man connected with the test must watch the machine continuously. He is responsible for seeing that accidents, due to excessive speed, cannot occur.

When using the shop apparatus, it is as important to take the same precautions in wiring and starting for test as are taken in the case of the apparatus for production. These precautions are detailed in the following pages.

Several of the shop motors used by the Testing Department are alternating current synchronous motors. In most cases, these are permanently connected to a direct current generator. It is often necessary, however, to erect and operate synchronous motors temporarily for production tests.

When starting a synchronous motor the precautions must be observed that are explained in the section on Synchronous Motors. They must always be run in the Testing Department at unity power factor, unless the special requirements of the test are such that this cannot be done. Since the greater number of these motors are occasionally operated under variable loads, the value of the field current should be watched to see that the armature current is of the proper value for unity power factor. Should a motor fall out of synchronism, in consequence of excessive overload, or otherwise, the armature circuit must be opened immediately to prevent injury to the winding from overheating. Where using shop generators and motors, their lubrication must be always inspected at starting and also at definite intervals during operation to keep the bearings cool and prevent overheating. In addition, the instructions on bearings given later must be observed.

Safety Devices

Speed limiting devices must be installed on all shop apparatus in the Testing Department in which excessive speed is possible. These speed limiting devices are permanently installed wherever possible. Wherever this cannot be done they should be used temporarily.

All speed limiting switches and their circuits which are connected to generators and motors must be regularly tested at least once each week. All emergency governors on shop turbines should be tested at least once every day to see that they trip properly.

Safety valves and atmospheric relief valves are also permanently located wherever necessary on permanent steam

piping. They should be installed whenever necessary on temporary piping in order to insure safety. Great care must be taken in locating these devices in reference to steam mains, air compressor work and air tanks. The tests and apparatus given above are vitally important for the safe operation of the testing equipment, and the head of the section must insist that they are closely followed.

Switchboards and Floor Stands

Section switchboards are connected to the permanent wiring to obtain flexibility. These are so designed as to minimize the amount of temporary wiring as much as possible. The switchboards are of two classes; *viz*, those connected to high voltage circuits (750 to 15,000 volts), and the low voltage switchboards.
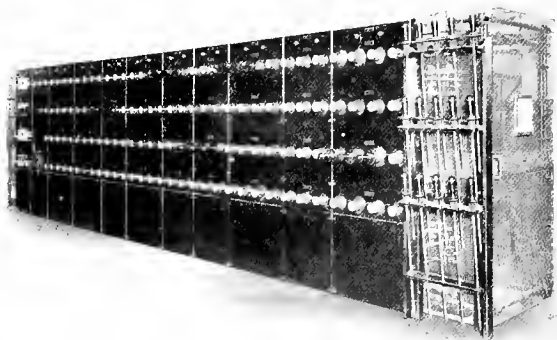

Fig. 4
FRONT OF HIGH TENSION SWITCHBOARD PLUG TYPE

The high voltage switchboards consist of a number of slate panels provided with high tension insulators, to which the permanent wiring terminals are attached leading from the permanently installed alternating current generators, transformers, and "floor stands." At some distance behind the slate front of the board, a second set of high tension insulators is carried on an iron frame, which are also fitted with terminals connected to lateral buses running throughout the length of the board. Since with this arrangement, generators, floor stands, and transformer terminals are located in vertical lines, whereas bus bar terminals are located laterally, it is possible to pass from one panel to any other panel on the board by inserting switches between the front and back sets of terminals. The metallic terminals used on these boards form the contact points for plug

switches. These plug switches are designed so that having removed or inserted a plug, all live parts are thoroughly protected.

Fig. 5

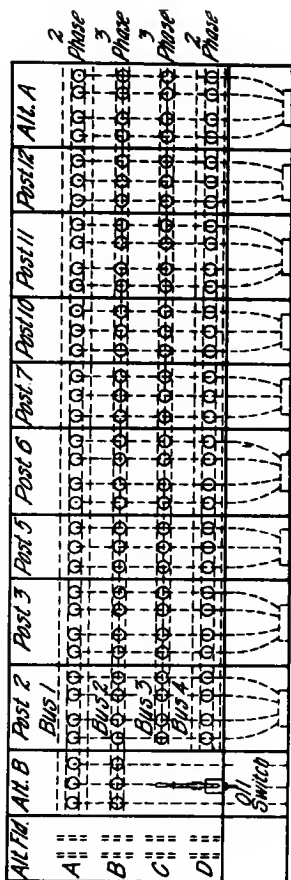WIRING DIAGRAM OF SECTION SWITCHBOARD

No plug switch must be used for connecting or disconnecting the front and back systems of contacts if there is any voltage on them. The switching system must be considered merely as a transfer scheme and must always be operated as such.

It will be readily seen by referring to Fig. 4 and to diagram, Fig. 5, that great flexibility is obtained, since any

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generator connected to a switchboard may be readily transferred to any "floor stand" or to any bank of transformers. Furthermore, any "floor stand" may be immediately connected with any other "floor stand" by merely inserting plug switches at the board.

"Floor stands" are so located in each testing section that all high voltage apparatus may be installed near them, thus reducing the length of high tension cable which is required for the machine in test to a few feet. The floor stands carry disconnecting switches and oil switches, through which the final connections can be made between their terminals and the terminals on the high tension switchboard panel.

Green and red "tell tale" lights are located on all switchboard panels and also on the "floor stands". They are automatically operated whenever an oil switch on the "floor stand," or a plug switch on the switchboard is opened or closed. When a red lamp is burning either at the "floor stand" or on the switchboard panel, it indicates that the terminals are in use, and connected to another circuit. If red lights are burning, it is, therefore, necessary to carefully investigate all panel connections before making any changes. When, however, a green lamp is burning it indicates that the panel, or "floor stand," is free, and may therefore be used. For example: A red light burning on the "floor stand" indicates that the oil switch has been closed on the corresponding "floor stand" panel and that the terminals of the "floor stand" panel are alive. Again, if a red light is burning on the "floor stand" its switchboard panel has been connected by the plug switches to another panel, consequently, the "floor stand" terminals may be alive. Hence, the red light acts as a danger signal. It should never be entirely trusted, however, and the same care should always be taken as though "tell tale lights" did not exist.

Connections are brought out at the top of the "floor stands" through high potential bushing insulators to terminal blocks mounted on the insulators. All this wiring is permanent. From the terminal blocks, temporary lines must be run to the high potential testing table. A second row of insulators is provided on the top of the "floor stands" which must only be used as strain insulators. The temporary cables running to the testing table must be securely fastened to these insulators. By this means the strain on the connections at the terminal blocks is relieved and wires cannot drop on to the floor if they become disconnected. The insulators are arranged so that cables can be taken off at any angle with a safe distance between them.

If temporary wiring has to be carried some distance, high potential pedestals must be used to support the spans as shown in Fig. 6.

The testing table shown in Fig. 6 is the standard type of high potential table used in the Testing Department. These tables are constructed so that all high potential wiring is protected, and it is impossible to make contact with it when the

table is in use. High voltage and low voltage circuits within the table are placed in separate compartments and insulated from each other. Tables are built of asbestos, wood, angel iron and expanded metal. The A.C. compartments contain an oil switch, potential transformers, current transformers, and a special transfer switch which has four different operating positions, viz.: (1) short circuit (2) synchronizing (3) three-phase (4) quarter-phase or three-phase and neutral. This
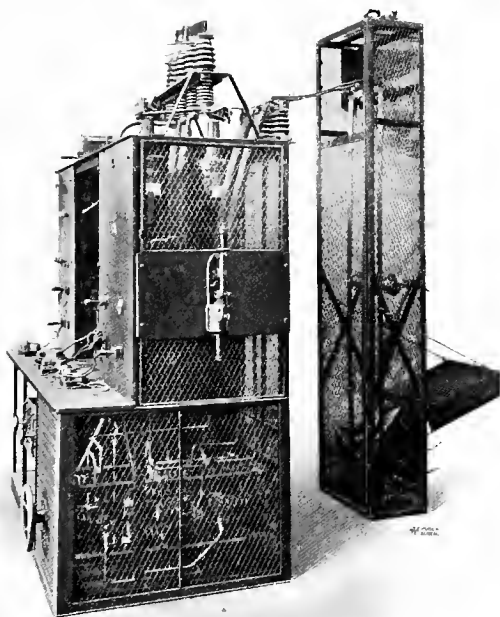
Fig. 6
HIGH POTENTIAL PEDESTAL AND TESTING TABLE

switch is interlocked with the oil switch so that it cannot be switched to the short circuiting position without first opening the oil switch. The alternator field must always be opened before turning the switch to short circuiting position.

High voltage connections are made at the top of the table as employed on high potential "floor stands". The secondaries of the current and potential transformers are connected to binding posts in their respective compartments, forming the

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terminals of the permanent wiring leading to the meters on the front or operating side of the test tables. All current transformers should have a capacity of 5 amperes for the secondary, and the potential transformers used should be enclosed in an iron case and oil cooled. Transformer secondaries should be kept grounded on one side when in use. A detailed print of the wiring circuit will be found mounted on each table. All meter switches and terminals are properly and plainly labeled showing their readings at each position of the transfer switch. All table wiring is permanent and insulated for a maximum working voltage of 15,000.

The D.C. compartment is wired for all the circuits of two D.C. machines for voltages not exceeding 750 volts. The table is furnished with double-pole 500 ampere 600 volt circuit breakers. For all currents above 300 amperes, terminals are provided for the standard ammeter shunts used in the Testing Department. When using currents above 500 amperes
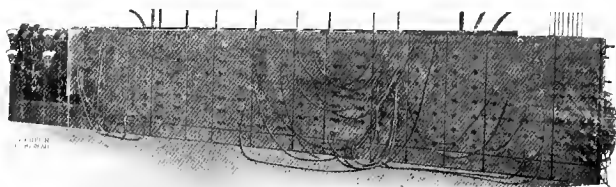

Fig. 7
FRONT OF D.C. SECTION SWITCHBOARD

the circuit breaker on the table must be cut out of circuit and breakers of larger capacity wired in the circuit external to the table. When D.C. currents are read direct, ammeter jacks are provided which allow the insertion or removal of the meter in circuit without interrupting the circuit.

Though these tables are fitted with safety devices and interlocks, etc., in order to render all protection possible, operators must treat them as if no protection exists. In other words, great attention must be given to all details of operation, and in no case should connections be changed by throwing switches, etc., unless the operator feels certain of the correctness of so doing.

All D.C. switchboards recently installed are of the plug terminal type, but they differ radically from the A.C. plug boards. The older D.C. boards are equipped with bolted terminals. Fig. 7 and Fig. 8 show the front and back views respectively of a direct current switchboard of the plug type. These boards carry terminals, circuit breakers and switches for all

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D.C. shop circuits. Switchboards are interconnected with each other and by means of underground cables are connected to small "pit switchboards" or "posts" or "floor stands" conveniently located. These are generally fitted with plug terminal connections, and are connected permanently to the D.C. switchboards. All exciter sets are also connected to the D.C. switchboards. Hence, any "stand," "pit," "exciter," etc., can be readily connected to any part of the test desired.

Where it is necessary to connect two cables together an insulated coupler should be used where possible. These couplers are intended to carry a maximum current of 600 amperes continuously. A greater current must not be carried continuously, otherwise overheating will result. Where it is necessary
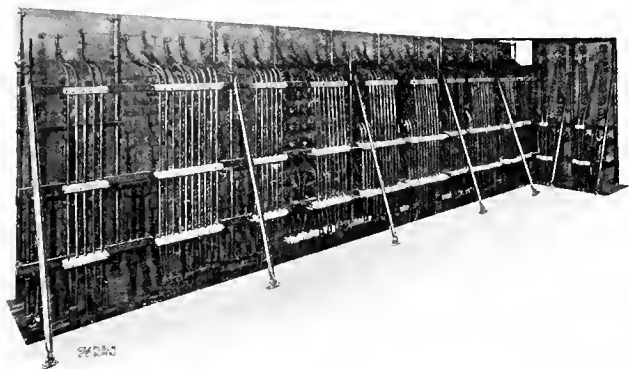
Fig. 8
BACK VIEW OF D.C. SECTION SWITCHBOARD

to carry more than 600 amperes, two or more cables must be used in multiple.

In making connections on any of the "plug boards" plugs must not be allowed to strike the slate panels and chip or crack them. See what connections are required, then carefully insert the plug in its receptacle, entering it to the locking position. If these precautions are taken the least damage will be done in case of short circuit. The ampere rating of each switchboard terminal is placed above it. No cables or terminal must be overloaded.

All field plugs must be carefully locked on insertion so they cannot accidentally be pulled out.

All "pits" and "stands" must be kept clean and free of rubbish.

Cables with defective insulation or having defective plug terminals must not be used, but must be sent by the head of section to the repair shop as soon as the defect appears. All cables must be kept on cable racks when not in use.

It is often necessary in testing to dissipate electrical energy through a resistance. When it is necessary to use resistances as a load for large machines, the water box has been found most convenient. The water box, as used in the Testing Department, is an iron box mounted on porcelain insulators. Suspended above the box by insulators is a triangular iron blade which can be lowered into the water box. When the water box has been filled and the resistance adjusted by the addition of salt, the resistance may be varied by lowering or raising the plate in the liquid which is admirably adapted to close adjustment.

The box is mounted on porcelain insulators; it should, however, always be considered as grounded. In connecting the boxes to grounded shop circuits, the grounded side should be connected to the cable leading to the box, and the ungrounded side should be connected to the water box plate. When using water boxes as a load on three-phase circuits, the cables leading from the box should be connected together to form a Y connection, and the phase cables should be connected to the plates.

Before loading a machine on a water box, the salt solution must be adjusted for the voltage and current required. To do this, apply a low voltage to the box and note the current. If this is not possible add fresh water to the solution until the resistance is sufficiently high to prevent an excessive rush of current when the bottom of the plate enters the solution.

The majority of water boxes in the Testing Department are equipped with hydraulic cylinders for operating the triangular plate. This consists of a vertical cylinder fitted with a piston and piston rod from which the plate is suspended. Water is forced into the cylinder, or released from it by two electrically operated valves, one for raising, and the other for lowering the plate. Small cables run from the electrical valves to a small distributing switchboard, whence leads may be carried to any of the testing tables, and connected to operating switches. Water boxes can be operated from any section by this method of remote control. If it is desired to operate water boxes in multiple, the cables leading to the control valves must be connected in multiple, and a single operating switch will control any number of boxes.

The Testing Department is equipped with many wire resistance boxes of small and moderate current capacity. The majority of these are field resistances of the standard enclosed card and tube type. These resistances are not grounded upon the frame, but should always be so treated in order to insure safety and freedom from accident. For this reason, the frames should always be insulated from one another and also from ground. All boxes are marked with their resistance and maximum current carrying capacity, so that the proper resistance for a test can be readily selected. Defective rheostats

must never be used in test, but must be immediately sent by the head of the section to the repair shop. Permanent motors are generally equipped with their own starting resistance. When starting motors for test, series resistances of large current carrying capacity must often be used. In such cases the water box is the best type of resistance. When starting motors with a water box the voltage drop across the resistance must be reduced to a small value before the motor is thrown directly across the line.

Unless special permission has been received more than 2300 volts must not be connected to water boxes unless they are especially insulated.

The standard water box used will dissipate 75 kw. continuously without excessive heating. If the water in the boxes is allowed to boil, the resistance regulation becomes very unsatisfactory. Arcing may then occur and set up electrical surges. Hence, the temperature of water boxes must always be kept well below the boiling point, either by allowing cold water to run into them continuously while under load, or if necessary by reducing the load.

To prevent arcs and therefore excessive voltage rises, water boxes must never be used to open alternating current circuits.

Each test section is equipped with permanent transformers. Additional transformers are also available for special tests, or for use when the regular transformers are in operation. Permanently installed transformers should be used whenever possible to save wiring cost and time and to obtain the advantages and safety afforded by permanent wiring. On the permanent banks of transformers the primary and secondary terminals are brought out to terminal boards with the plug switches for making the various transformer coil connections required with the cables leading to and from the bank. The primary terminal boards are insulated for 15,000 volts between lines, and any combination ordinarily desired can be obtained by inserting plugs in the proper terminals. The plug switches must be considered only as a ready method of connecting up the transformer coils. *They must not be used for connecting or disconnecting live circuits.* The boards are thoroughly insulated, but must always be treated as unprotected, when high voltages are used.

The secondary coils are connected to a low tension plug type switchboard where they may be connected by plug terminals to cables running to any part of the test. Each plug terminal is labeled so that no wrong connection should be possible, if ordinary care is observed.

If temporary transformers are used, they must be properly installed and wired so that safe operation is secured. All cases must be grounded by substantial ground wires or cables, the case and ground terminals must be in good condition and fitted so that they cannot work loose. Never sit or stand on the top of a transformer when connecting or disconnecting it. Always

use step ladders for this purpose and see that the transformer is not alive before touching its leads or terminals.

The following example illustrates the general procedure to be followed in the wiring of high voltage alternating current circuits. To connect a shop alternator to a high voltage machine on the testing floor near the high potential "floor stand", see that the oil and disconnecting switches are open, then connect the alternator using the armature terminal board to give the proper voltage and phase combination. Connect the machine by temporary wiring to the high potential terminals on the "floor stand". When the machine is ready to start a transfer bus should be selected which is not in use on the high potential switchboard. The alternator armature is then plugged in on the transfer bus, after noting that the alternator oil switch is open. Next plug the panel connected to the proper floor stand to the same bus, and close the alternator oil switch. On closing the circuit at the "floor stand" panel, a red lamp lights up and indicates that the connection of the alternator has been made up to this point. The disconnecting switches should then be closed at the floor stand. Finally, the oil switch on the floor stand is closed and a red light burns on the corresponding panel of the high potential switchboard, showing that the panel is connected through the high potential floor stand to the circuit. The oil switch in the test table must be employed to open and close the high tension circuits, if required during the test. In all cases oil switches should be used to "make" or "break" alternating current circuits, where such circuits carry an appreciable amount of current.

In all high voltage work proper precautions should always be taken to insure against accident in handling circuits. In all cases where temporary circuits of high voltage are used, they must be thoroughly protected by mechanical barriers and danger signals; and white tape should be used wherever it is advantageous as an additional warning.

Blocking

The cast iron bases, blocks, beams, etc., used to furnish temporary test foundations for machines in test, are called blockings.

In setting up self-contained machines the only blocking required is that necessary to raise the stator off the floor. The blocking should be located so that the bearings and frame are well supported. The blocking should be as low as possible and the necessary height should be obtained in as few sections as possible.

Many machines are built without base, shaft or bearings, and the test blocking must be arranged to meet such conditions. All blocking must be securely clamped or bolted in place, the latter method being preferable. The height of blocking is determined by measuring the distance from the supporting foot to the bottom of the stator.

Shafts

All self-contained machines are tested on their own shafts. The assembling of the shaft in the rotor will be discussed later.

Machines without base, shaft or bearings require the use of a temporary or shop shaft and bushings of the right size to fit the shaft and the bore of the rotor.

In assembling shop shafts in rotors, care must be taken to see that the shaft and the bore are clean and free from burrs. Lubricate the shaft, and cover well with oil or a mixture of white lead and lard oil, and put one bushing on the shaft. Insert the shaft into the rotor and slip the other bushing in from the other end of the rotor hub.

On all shop shafts the revolving armature or field is kept in place by some form of clamp collar on the shaft. This collar must not obstruct the air passage through the armature spider. In assembling the shafts in the rotors of a self-contained machine take the same precautions as given above. The rotor is conveniently located on the shaft by measuring the distance of the end of the shaft from the hub, but since the hubs are not machined exactly to dimensions it is important to measure the distance from several points on the center line of the punchings to the back end of the hub, and then from this information lay out on the shaft the position the hub will occupy when in place on the shaft.

The shaft is usually started into the bore with a heavy ram. A piece of fibre or other suitable substance must be used between the end of the ram and shaft to prevent injury. The shaft and rotor are then placed in a hydraulic press and arrangements made for pressing. The pressure applied should be watched and when the shaft reaches the exact location in the rotor the pressure must be instantly cut off.

The usual pressure used on shafts is about five (5) tons per inch of diameter of shaft. If a pressure of only four (4) tons is required it will pass. Below this amount the superintendent responsible must decide whether it will pass or whether to put set screws through the hub into the key or employ some other method to hold the rotor securely on the shaft.

Allowances for the fit of shafts are given on the following blueprints.

M 181183 Master Sheet
M 205170 Ry. Motor Shafts
M 215205 D.C. Machines
M 181182 Turbine Shafts
M 215201 Miscellaneous
M 215203 Journals
M 208908 Horizontal A.C. Machines
M 208903 Vertical Machines

The bore is usually made to a standard pin gauge, and these tables show how much larger a diameter than the bore the shaft should have to give the required pressure.

It frequently occurs that a shaft carries an extension beyond its bearing housings which is fitted with key and keyway.

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t is then essential, for safety, that the ends of the shaft should be protected by a mechanical guard. The key must either be removed from the shaft or securely held in position. If shafts carry one-half coupling, pulley with set screws, bushings, clamps or collars with projecting edges they must, in all cases, be protected with barriers, to prevent injury from contact with them.

Bushings

It is necessary that test shaft bushings be bored .002 larger than the shaft and that their external diameter be .002 smaller than the bore of the rotor. Hence the shaft will fit loosely in the rotor. This, though immaterial on most large machines, is sometimes troublesome on small ones, especially small direct current machines. For this reason, a shaft should be used without bushings wherever possible.

Couplings

Shop couplings are usually a loose fit on test shafts and they should always be secured in place with a set screw. Wherever two shafts are to be direct connected by a flange coupling, the face of the coupling should be trued up in a lathe after the coupling is on the shaft. Standard dimensions of C.I. coupling may be found on General Electric Company Drawing M-215200. In connecting two shafts by a flange coupling the face of each coupling revolves in a plane perpendicular to the center line of the shaft, and the center line of one shaft is a continuation of the center line of the other. The first condition is insured by facing off the coupling after it is pressed on the shaft, the shaft being turned on centers in a lathe. The second condition is obtained in various ways. For example the bearings in which the shafts turn may be located and lined up by stretching a ine wire between the centers of the two outboard bearings and adjusting the position of the other bearings to this line. In this case, allowance must be made for the natural sag of the line, which depends on the length and tightness of the line. For tables of sag and method of using steel wire for aligning shafts, see article by A. H. Nourse in the *American Machinist* of March 5th, 1908.

The usual method in the Testing Department of lining up two shafts with flange couplings, is to bring one coupling up to the face of the other and as nearly into the correct position as can be judged by the eye, and then to move the pillow block by a bar or jack until the faces of the couplings are exactly parallel to each other. This condition can be determined by gauging the distance between the faces. If a gauge can just be inserted in the space between the coupling at several different points, the faces are parallel. The height can be adjusted very readily as it is usual to have the couplings made with a projecting ring on the face of one half and a corresponding recess in the face of the other one. Care should be taken to see that the coupling bolts are a good fit in the holes, otherwise

each bolt may not be equally stressed and some bolts may shear off.

Several designs of flexible couplings exist; but two types are much used in the works. One coupling consists of two parts of four arms each, the arms of one part interlocking with those of the other. These arms are separated by rubber buffers. The other type has its two parts laced together by a leather belt. This coupling is shown on drawings:

M 217661	M 217674
M 217662	M 217675

In flexibly connecting two shafts together the shafts need not be exactly in line, although they should be so adjusted as closely as possible, without spending too much time on the alignment.

Leather Belts

Leather belting is much used in the Testing Department, and a considerable amount of power is often transmitted by belts. In no case, however, should more than 400 kw. be transmitted by a belt unless special permission has been received. Wherever possible endless belts should be used. If laced belts are necessary the laces must be carefully examined before starting the test, and if they are used for any considerable length of time, at or near their normal rating, the belt should be frequently examined to make sure that the lace is holding properly. The breaking or parting of a belt when large amounts of power are being transmitted may seriously damage apparatus, or injure men working about the test. Belts must, therefore, always be regarded as a source of danger and possible accident.

Whenever belts are running near an aisle, or passage way, guards must be so placed that men cannot be thrown, fall, or drawn into them. The testing tables should never be set in a line with a running belt and work should be so arranged that an employee need not work continuously in line with belts, unless proper mechanical guards are provided. A defective belt must never be used in testing work. Whenever a belt is found defective, it must be returned to the Repair Shop for repairs. Care should be taken to see that belts of proper capacity are selected for a given load. Fig. 9 and the Data Sheet on page 26 show the carrying capacity of leather belts of various widths and thicknesses when running at speeds of from 1000 to 5000 ft. per minute. It is not permissible to operate a belt in the Testing Department at a higher velocity than 5500 ft. per minute.

When a belt is started for the first time it must be very carefully watched to see that it runs properly on the pulley, and has the proper tension. Under no circumstances must an employee lean against, sit or stand upon, or pass through a belt even though it is not running. It is equally important that neither tools, nor articles of any description should be laid upon belts after they are located on the pulleys.

DATA IN CONNECTION WITH WIDTH OF LEATHER BELTS

The curves in Fig. 9 have been plotted from the following data:

Coefficient of friction = .4.
Arc of Contact = 165°.
Weight of leather belting = 56 lbs. per cubic foot.
Centrifugal force = .012 V^2 (with velocity in ft. per second).
$T_1 = 1.$ $T_2 = .316.$
Ratio tight over slack side = $\dfrac{T_1}{T_2} = 3.1643.$
Torque or pull = $T_1 - T_2 = .684.$
Greatest tension = $T_1 + .012 V^2.$
Average thickness per ply = $\frac{3}{16}$ in.
Working tension per sq. in. = 275 lbs. for laced belting.
H.p. or kw. per inch in width of $\frac{3}{16}$ in. thick.

1.05	.783	for 1000 ft. per minute.
1.56	1.163	for 1500 ft. per minute.
2.03	1.514	for 2000 ft. per minute.
2.46	1.835	for 2500 ft. per minute.
2.855	2.129	for 3000 ft. per minute.
3.18	2.372	for 3500 ft. per minute.
3.447	2.57	for 4000 ft. per minute.
3.63	2.71	for 4500 ft. per minute.
3.73	2.78	for 5000 ft. per minute.

Width of Belt	Curves Plotted with the Following Thickness
Up to 6 in.	1 ply belting varying from $\frac{3}{32}$ in. to $\frac{9}{32}$ in.
6 in. to 20 in.	2 ply belting varying from $\frac{9}{32}$ in. to $\frac{15}{32}$ in.
20 in. to 40 in.	3 ply belting varying from $\frac{15}{32}$ in. to $\frac{21}{32}$ in.
40 in. to 60 in.	4 ply belting varying from $\frac{21}{32}$ in. to $\frac{27}{32}$ in.
60 in. to 80 in.	5 ply belting varying from $\frac{27}{32}$ in. to $1\frac{1}{32}$ in.

Belts are to be Used in the Following Widths

Up to 2 in.	varying by $\frac{1}{4}$ in.
2 in. to 5 in.	varying by $\frac{1}{2}$ in.
5 in. to 10 in.	varying by 1 in.
10 in. to 36 in.	varying by 2 in.
Above 36 in.	varying by 4 in.

Pulley Face to Exceed Width of Belt

Up to 2 in.	+ $\frac{1}{4}$ in.
2 in. to 5 in.	+ $\frac{1}{2}$ in.
5 in. to 10 in.	+ $\frac{3}{4}$ in.
10 in. to 24 in.	+ 1 in.
24 in. to 36 in.	+ $1\frac{1}{2}$ in.
Above 36 in.	+ 2 in.

Before starting a belt, the man responsible for the test must see that no one is in contact with the belt and that nothing has been left lying upon it or where it may fall into it, while running.
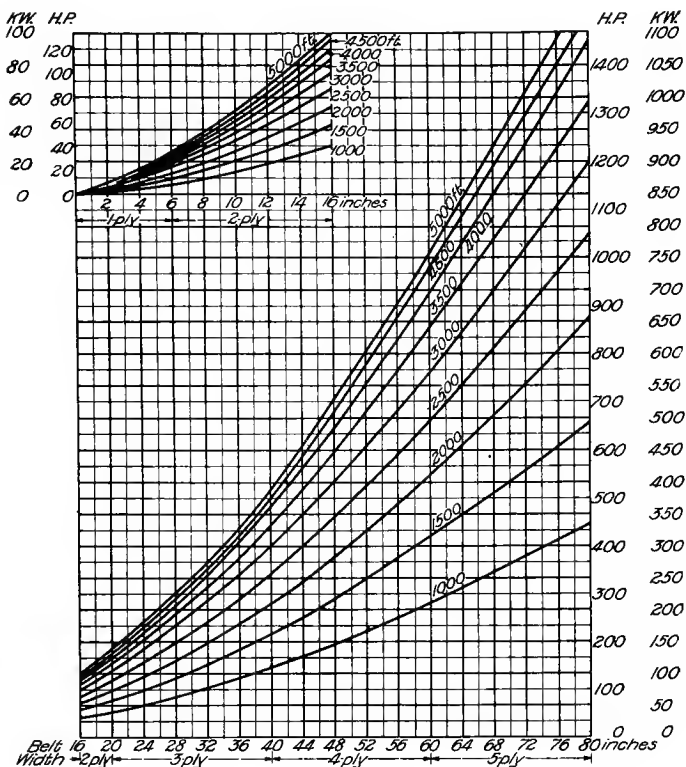

Fig. 9
WIDTH OF LEATHER BELTS

Care of Testing Instruments

All measuring instruments for testing work must be obtained from the general instrument room, or from branch instrument rooms located in several of the testing sections. The instruments, while in this instrument room, are in the charge of a man who

is responsible for their condition and calibration before being given out for testing work. When instruments are taken from the instrument room by the tester he must receipt for them to the man in charge of the instrument room, and be responsible for the proper use and care of same. In all cases, the man signing for testing instruments must be responsible for their return to the instrument room in as good condition as they were received by him. In case instruments are damaged, a report must be immediately made out by the man in whose charge they are and turned in with the instrument to the man in charge of the instrument room.

In order that results of tests may be consistent and accurate, all instruments must read as nearly correct as possible.

Constants and curves must also be at hand for correcting instrument readings and reducing them to absolute values. Many instruments are provided with permanent magnets which must be maintained at constant strength to insure accuracy. None of these instruments must therefore be carried through strong magnetic fields.

Practically all indicating instruments have their movable parts supported by jeweled bearings, hence, these instruments must be handled as carefully as a watch. When using meters the wiring should be so arranged that they are out of circuit when readings are not required, otherwise heating errors may arise.

When a meter is switched into circuit its maximum scale reading must not be exceeded, otherwise the needle may be bent and distorted. D.C. instruments must be connected so that the needle deflects in the proper direction when connected to a direct current source to prevent the needle being thrown in the wrong direction and bent.

Many electrical instruments used for testing work are affected by stray fields. The ordinary indicating wattmeter is extremely sensitive to such influences. Care should be taken, therefore, when using meters to see that readings are not influenced by stray fields.

These precautions apply in general to the use of electrical instruments, but do not include all the precautions which must be taken. Intelligence must always be used when using meters and measuring devices. Precautions which apply especially to certain types of apparatus will be noted in the following pages referring to various instruments employed. *It must be noted that, while the metallic case of a testing instrument is presumably insulated from terminals and current carrying parts, it may become accidentally grounded. When using such instruments, therefore, on high potential circuits, the tester should always remember that this condition may occur. He should, therefore, consider that the case is at the same potential as its terminals. He should never touch the metallic case of instruments when they are connected to high potential circuits. If it becomes necessary to tap an instrument case to see if the needle is sticking, small insulating rods must be used.*

Phase Rotation Meters

The general form of phase rotation meter is shown in Fig. 10.

It consists of a laminated iron ring with four windings about 90° apart.

For two-phase all four windings are used, while for three-phase but three are used. The terminals are stamped 1, 2, 3, 4, and should be connected to corresponding terminals on the A.C. machine under test. These meters are intended to run from the residual magnetism of the machine alone.

The rotor consists of a bar pivoted at the center. This bar should rotate in the same direction as the machine under test. While this is the general principle of the meter, there are several forms used in the department. They should all
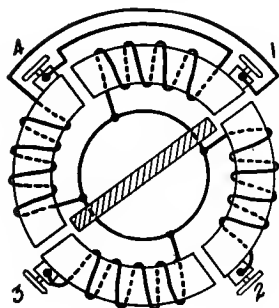

Fig. 10
PHASE ROTATION METER

be operated, however, from the residual magnetism of the machine.

The above sketch, though somewhat out of proportion, shows the general construction of the meter. The phase angles are not absolutely correct but are sufficiently accurate for practical purposes.

The Compass or magnetic needles used for indicating polarity are of the ordinary commercial type. This instrument is not used very frequently in the testing department since there is danger of its polarity being reversed in strong magnetic fields. Care must therefore be taken when using.

Steam Engine Indicators are of the standard commercial type and are used to take indicator cards generally on marine engines. The following points must be considered. The connecting cord must not stretch, the indicator cylinder must move freely, the paper must be smooth and held firmly on the cylinder, and the pencil must mark plainly and move freely.

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The size of spring used in the indicator must be selected so as to give as large a card as possible. Generally speaking, the larger the card the more accurate the results. The spring must be kept in good condition and must be frequently calibrated in order to insure accurate results.

A Planimeter should be used to measure the area of indicator cards.

In using it always set the vernier and scale at zero. The pivot point should be securely located and the tracer moved in one direction around the indicator card back to the starting point. The roller wheel should roll on a flat unglazed surface to secure accurate results.

Balances and Scales

In using balances and scales the no load position should always be noted, as a zero error may exist. Always hold balances, when measuring, by the hook at the top. After using platform scales the beam should always be either dropped or locked to avoid damage to knife edges, which a blow may otherwise cause. All scales and balances used for important readings must be frequently checked against standard weights in order to insure accuracy.

Manometers and Air Meters

Manometers are used for measuring low air pressures, *i.e.*, up to 4 or 5 ounces. For measuring pressures up to 2 ounces they consist of two vertical glass cylinders located parallel to each other upon a proper base through which a connection is made from one leg to the other. The glass cylinders or "legs" are partially filled with water. In some cases the two legs have a cross section ratio of 10 : 1. When pressure is applied above the water in one leg the water is forced downward and the water in the other leg rises a corresponding amount. Hence, when the cross section of the legs is the same the pressure is equivalent to the difference in level between the water in the two legs, whereas if the ratio of cross sections is 10   1, a water rise in the small leg will measure a pressure equivalent to a water column 1.1 times the height read. Such an arrangement permits of accurate observation of pressures. The difference in water levels is generally read on a "hook" gauge provided with a properly arranged screw and corresponding scales.

The common "U" tube, consisting of a glass tube bent in the form of a letter "U," is frequently employed. One side of the tube carries a scale, by which the difference in height of water in the two legs can be read. In all cases the zero point must be carefully noted, before applying pressure. This reading must be added or subtracted, as the case may be, from pressure readings.

Anemometers are used to measure the velocity of air. Such meters are not very accurate even at their best and must not be used where accurate results are desired. In such cases

the calibrated orifice or "pitot" tube method of making air measurements must be employed.

Pressure and Vacuum Gauges

Pressure gauges must not be subjected to extreme heat, otherwise their accuracy will be affected. With steam pressure gauges, "U" shaped or circular loops must be used in the pressure pipes leading to the gauge. These form a trap that holds sufficient water to fill the operating spring of the gauge, thus protecting it against the high temperature of the live steam and keeping it comparatively cool. Vacuum gauges must also not be subjected to extreme heat. All gauges must be regularly checked with standards to make sure they are correct when used on important work.
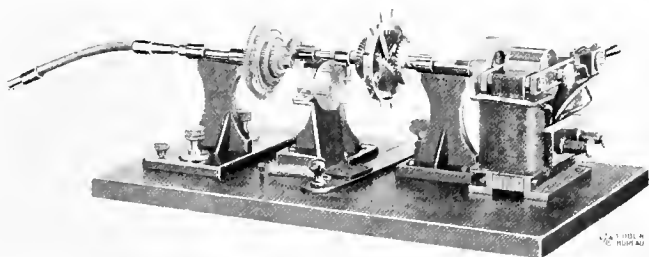

Fig. 11
SLIP MEASURING DEVICE

The Hydrometer is used to measure the specific density of liquids. It is generally used in the testing department in connection with storage batteries to insure that the electrolyte is kept at the proper density.

Slip Machine

For accurately measuring the slip of an induction motor, for all conditions of load, the slip indicator shown in Fig. 11 is employed. This indicator mechanically compares the angular velocities of two revolving shafts, one of which is driven at constant speed by a synchronous motor, and the other at the speed of the motor under test, to which it is connected by a flexible coupling.

The indicator is mounted on a slate base, fitted with a handle at each end, for carrying or handling it. The synchronous motor is very simple in construction. It has a bipolar stator, and a four-pole rotor without winding. The shaft carries a fly-wheel on one end and on the other a 32 tooth brass gear

wheel, which may be made to mesh with any one of a nest of seven gears, mounted on a parallel shaft, by shifting the motor on the brass plate. By loosening two screws passing through slots in the sole plate of the motor, the latter may be shifted to any desired position, exact alignment being secured by dowel pins. The various gears are provided to enable the synchronous motor to drive the parallel shaft at different speeds, thus adapting the instrument for testing motors with various numbers of poles.

The parallel shaft is equipped at its other end with a bevel gear wheel meshing with two pinions of a differential gear. Meshing with these pinions on the other side is another bevel gear, carried on a shaft the other end of which carries the flexible coupling by which it is connected to the machine in test. A short auxiliary shaft behind the differential gear has, on one end, a gear wheel meshing with the large wheel of the differential gear, and on the other end a small handwheel by which to hold this shaft.

A clutch, operated by a lever, connects the auxiliary shaft to a cyclometer which registers the number of revolutions of the auxiliary shaft. The gear ratio makes one revolution of the auxiliary shaft equal to one-half revolution of the differential gear.

The indicator is used as follows:

With the voltage normal and the speed of the alternator held constant at normal frequency of the motor, the indicator is connected to the induction motor shaft by means of a "split tip." The bevel gear, on the shaft carrying the split tip, is driven at the speed of the induction motor. By holding the large gear of the differential stationary by grasping the hand wheel on the auxiliary shaft, the synchronous motor is mechanically brought up to the speed of the induction motor by power transmitted through the other side of the differential and the nest of gears. On closing the line switch on the synchronous motor it will immediately fall into step with the alternators and run at synchronous speed. Should it fail to do so on the first trial, a second or third trial in the same way will usually be successful. With the synchronous motor running and driving one bevel gear of the differential at synchronous speed, and the induction motor driving the other bevel gear at the speed of the induction motor, the large gear of the differential will rotate and drive the auxiliary shaft and cyclometer. In this way, the difference between synchronous speed and the speed of the induction motor is mechanically recorded, and it is only necessary to read the cyclometer for some definite length of time (usually one minute) to know the exact number of revolutions by which the two speeds differ.

In Fig. 11 the gear wheel of the synchronous motor shaft is shown meshed with the gear wheel of the "nest" having the same number of teeth (32), adapting the indicator to test a four-pole induction motor, since the rotor of the synchronous motor has four poles. The other gears of the "nest" have

16, 48, 64, 80, 96 and 112 teeth, respectively, providing for testing induction motors with the various numbers of poles, commonly built.

The Ballistic Galvanometer

The Ballistic Galvanometer when used to measure magnetic flux or electric quantity must be supported on a pier to eliminate vibration. It may be located either beside the apparatus under test, if a pier is available at that place, or at a distance, usually in the laboratory.

In measuring magnetic flux an exploring coil, usually of a few turns only, is employed enclosing the flux at any convenient point. As the exploring coil voltages are ordinarily very low, no particular care is required for insulation except to guard against mechanical abrasion.

The method for obtaining the necessary change of flux may be either by withdrawing an exploring coil, by reversing the current producing the flux, or by making or breaking the current. For permanent magnets the first is the only way possible. For electromagnets the second method is the more usual, the exploring coil being wound permanently in place. If the current is broken without reversal, the measurement is subject to an error due to residual magnetism; which in a continuous iron circuit (no air gap as in a stack of ring punchings) sometimes gives a remanence of over three quarters of the whole flux (as may be seen in a hysteresis loop). Similarly if the current is made an error only occurs if the flux does not start from zero value.

The expression for computing the flux is $F = kRD/N$, where k is the constant of the galvanometer, R the resistance (external + galvanometer resistance), D the observed deflection, N the number of turns of the exploring coil. If the galvanometer is one with considerable damping, k will vary greatly with the resistance, being constant only at high resistances, and the curve or table giving the K values must be referred to. If only relative values of flux are required, for instance, the variation of flux with generator field current, no value of K need be obtained, the flux being proportional to RD, the product of resistance and deflection.

In computing the flux it is necessary to note carefully whether, as is usually the case, the constant of the galvanometer is given for a reversed current, and whether the observations correspond. For instance, in calibrating, the current is usually reversed, and flux observations of a permanent magnet made by withdrawing the coil must always be multiplied by two, if the ordinary K of the galvanometer is used.

When observing quantitatively, see that the whole flux change occurs before the galvanometer coil has moved through any considerable portion of its swing. This is readily tested by waiting a fraction of the galvanometer period, perhaps a second or two, before pressing the key, after which there should be no deflection.

The swing of the galvanometer coil is stopped either by short circuiting through a proper key, if the galvanometer is damped considerably, or by a counter torque obtained by applying a small fraction of the voltage of a cell through a suitable reversing key in the proper direction.

The calibration of the ballistic galvanometer is usually accomplished by reversing the current in a long air solenoid with an exploring coil surrounding the middle. The flux at the middle of the solenoid is $4\pi nAI/10$, where n is the number of turns of the solenoid per cm., A the area and I the current (in amperes).

SPEED AND FREQUENCY

The primary standard for speed is an accurate speed counter and a reliable chronometer. The Company's chronometer is checked by Washington time, as time record is made on the laboratory through a special wire, daily at noon.

Secondary or Working Standard

The Company's working standard is a liquid tachometer having a scale 36 inches long and graduated from 300 to 1200 revolutions per minute. This tachometer is coupled to a small motor which can be run in either direction. The tachometer to be tested is connected to the other end of the motor. In case it is desired to read speeds above or below this range, a system of gears is employed for increasing or decreasing the speed. This working standard is checked semi-monthly by the standard speed counter and a watch which has been compared with the chronometer.

The secondary or working standard for the frequency indicator is a current interrupter of the vibration type, operated by the working standard tachometer and motor. For the Thomson station type, a machine running at the required frequency, checked by a speed counter and watch, constitutes the working standard.

Tachometer and Frequency Indicators for Testing

The Company has in use the following types:

Veeder Liquid; Schaeffer & Budenburg (portable); Niagara (portable), and Vibration Tachometer for frequency indicators, the Hartmann and Kempf portable frequency indicator; for testing stands, etc., the G.E. Type H Thomson Frequency and Speed Indicators.

In using any portable tachometer care should be taken to have them checked by running in both directions, as it is frequently found that they differ somewhat in their calibration whether run clockwise or counterclockwise. By clockwise is meant clockwise rotation of the tachometer shaft looking from the spindle end.

Tachometers like the S.&B. and Niagara types when run continuously need oiling every 3 or 4 hours. The best grade of

clock oil only should be used on them. This type, although it is apparently strong and compact, is nevertheless a delicate instrument and should be handled as carefully as any other measuring instrument.

The Veeder liquid tachometer is a centrifugal pump arranged to pump the liquid from a small reservoir into a glass tube, the height of the liquid in the tube rising or falling with the speed. This type of tachometer has a small plug that can be screwed into or out of the reservoir, changing the level of the liquid in the reservoir and tube by displacing some of the liquid in the reservoir and thereby adjusting the zero. In the later types of Veeder tachometers, the zero is the lower surface of the inverted cone at the foot of the glass tube in the reservoir. The meniscus of the liquid in the column should be level with the lower surface of this cone. The liquid used is *grain alcohol* slightly colored with red aniline dye. Wood alcohol should not be used as it corrodes the shaft, causing the bearings to leak. If the tachometer leaks, it should be returned to the Standardizing Laboratory to be repacked.

There are two kinds of vibration tachometers; one is tuned to respond to the vibration of the machine, due to the speed; the other is an electromagnetic type operated on 110 volts. The former, however, is not satisfactory where more than one machine is running, as the reeds respond to the vibration of a machine adjacent to the one being tested. Electromagnetic type can be used conveniently when an accurate speed measurement is required at some distance from the machine. Not more than the rated voltage should be applied, as excessive voltage will cause a burn out.

G.E. Type H Frequency and Speed Indicators

These are a switchboard type of instrument, convenient for use on testing stands. The two instruments differ in the scale only, one being graduated to read frequency and the other the normal speed and a certain high and low percentage of the machine speed on which it is used. In using these instruments, adjustments for wave shape must be made by shifting the arms on the resistance box used with the instrument before beginning a test. This can be done by measuring the speed of the machine by means of a speed counter and watch, and moving the arms until the instrument reads correctly. Both of these types are iron clad (shielded) instruments, and, therefore, they are not affected by stray fields.

Hartman and Kempf Frequency Indicators

These are similar to the electrically operated vibration tachometer, but are graduated to read frequency. They have a voltage range from 230 down to 50 volts, a small button being provided on the end for cutting in or out resistance. When connecting, the button should always be in the 230 volt position, and after connection is made, the button should

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be turned until the right amount of resistance has been cut out to correspond to the voltage applied.

Wave Meters

Wave shape is taken either by wave-meter or by oscillograph.

In the wave-meter a synchronous motor is used carrying a contactor which makes contact at one point on the cycle, charging a condenser to the potential of the corresponding point of the wave; the condenser discharges through a photographic galvanometer, when the contactor brush is not at the charging point. The charging point is moved slowly (about one minute) through a cycle, the condenser receiving charges proportional to the potential of successive points on the wave, and the galvanometer deflection varying proportionately. The plate is connected mechanically to the contactor frame and is pulled slowly along as the charging point moves forward.

The instrument is mounted permanently in the laboratory (Building No. 4), and potential must be transmitted over the lines provided.

Voltage required is about 110 volts (90 to 150 volts).

It is necessary to provide for a current of about 4 amps. (at 110 volts) for the synchronous motor, not allowing a drop of more than a few per cent. in voltage. A good arrangement where practicable is to provide two potential tansformers, each connected separately to the laboratory. In this case a considerable voltage drop in the synchronous motor circuit does not affect the wave on the other circuit.

In taking wave shapes the speed and voltage must be held at their proper values without changing their values suddenly, to prevent hunting of the synchronous motor.

The Oscillograph requires a current of about 2 amps., at a voltage of about 110 volts. When, however, occasion requires the voltage can be within wide limits, as 20 to 200 volts.

The instrument is portable, and when no line to the laboratory is available, it can be located near the machine. A d.c. source at about 125 volts (90 to 150 volts) is necessary for the lantern arc and galvanometer field, which will give a current of about 6 amperes.

Wave Shapes in General

The term wave shape is used to denote the generator potential wave, at no load. Generator potential waves at various loads of unity or other power factors are sometimes required, and potential waves may be required on any portion of a circuit.

Current waves are generally taken with an oscillograph connected across a shunt (as is the case in a millivoltmeter). The resistance of the shunt should be selected to give a shunt potential drop of at least .2 volts.

The flux distribution on generator or motor pole faces is determined by obtaining the potential wave of a narrow exploring coil, usually of only a few turns, on the armature.

When two or even three waves are required together, taken in their proper phase relation, such as the potential and current waves of a reactance coil, the oscillograph is used. (The instrument is regularly built as a three-element oscillograph, *i.e.*, has three independent elements or circuits). The insulation between the elements is sufficient to stand several times the ordinary 110 volts.

The oscillograph is generally used for wave shapes, except when taking generator potential waves. Where a series of waves is required, the oscillograph is usually brought near the machine or apparatus under test.

RESISTANCE MEASUREMENTS

Unit employed	(Primary Std.)	(Coils from N.B.S.)
(International Ohm)	(Working Std.)	(Current Carrying Stds.)
Medium .01 to 1000000	{ Wheatstone Bridge Slide Wire	{ P.O. Dial or Decade Ohm Meter Special Bridges
Low Below 5	{ Thomson Bridge Drop Method	{ Voltmeter and Ammeter Quick Period Galvanometer Low Resistance Outfit
High above 50000	{ High Resistance D.C. Voltmeter Insulation Measuring Outfits	

Unit Employed

The unit employed is known as the "International Ohm". It is represented by the resistance offered to an unvarying electric current by a column of mercury at 0 deg. C., 14.4521 gm. in mass, of a uniform cross-sectional area, and 106.3 cm. in length." The cross-sectional area of this column is approximately 1 sq. millimeter.

Primary Standard

The Company's primary standards consist of two 1 ohm units which are occasionally compared with the Government standards at Washington and certified to by the Bureau of Standards. The certificates give the temperature at which the units are correct and also the temperature coefficient, *i.e.*, a correction factor to apply when the temperature of the unit differs from the standardizing temperature.

Working Standards

These consist of several current carrying units of various current capacities and resistance values. They are frequently compared with the primary standards referred to and also with each other.

CLASSES OF RESISTANCE MEASUREMENTS

There are three general classes into which resistance measurements may be divided. These are "Medium," covering a range from .01 to 1,000,000 ohms; "Low," covering a range below 5 ohms; and "High," covering a range above 50,000 ohms. It will be noted that the division line between the classes is not very definite, *i.e.*, the several ranges overlap each other.

Medium

For the measurement of medium resistance the "Wheatstone Bridge" and the "Slide Wire Bridge" are used.

WHEATSTONE BRIDGE

Two types are in use, the "Post Office" pattern and the "Decade" type. Both operate on the same principle. In the "Post Office" type the resistances composing the rheostat are all connected in series and the reading is obtained by adding *all* the values of the plugs that are *out* when a balance is obtained. In the "Decade" type (also the dial type) only one plug is used for each decade, and the reading is obtained directly, by noting the values against the plugs that are *in* when a balance is obtained. It is, of course, understood that in both cases proper account must be taken of the ratios as plugged in the "arms" of the bridge. Also, in both cases, only one plug in each arm must be used and the values must be taken from the plugs that are *in*. The following remarks will apply to both types of bridge.

Good Contacts

All plugs and other contacts should be kept clean and bright. The plugs should be cleaned every time the bridge is used or, if in constant use, at least every day. This may be done by wiping them with a piece of soft cloth or waste applied with the finger. *Never* use emery cloth nor polishing powder. The key contacts may be cleaned by putting a piece of heavy paper between them, pressing the key and pulling the paper out. If very much corroded, a piece of worn *crocus* (not emery) cloth may be used.

It is essential that all plugs should be tight. It is not necessary to use much force, in fact this should not be done. The plug should be given a slight rotary motion, at the same time applying a gentle pressure. In removing the plugs, give them a rotary motion in the *same direction* as when they were inserted. The rotary motion should be in a clockwise direction, to prevent unscrewing the plug heads.

Using Keys

To open the keys (if they are in proper condition) only a firm steady pressure is necessary. Pounding the keys must not

be allowed, since it ruins them. This applies to all testing keys, as well as to bridge keys.

Choice of Ratios

In using the Wheatstone Bridge, it is best that the resistance in the arms and the resistance in each of the four bridge arms should be as nearly equal as possible, as this gives the most sensitive arrangement.

Most bridges have a capacity of 1 to 9999 or 10,000 ohms in the rheostat, with ratios for multiplying or dividing the rheostat plugging by 1000. It is not advisable where other means are at hand to use the 1/1000 or 1000/1 ratios, except on a bridge of unusually accurate resistance adjustments, as the 1 ohm coils are not as accurate as those of greater resistance. Avoid using 1 ohm coils as far as possible.

TEMPERATURE COEFFICIENT

For ordinary bridge work in the factory and in general work (outside of the laboratory) the temperature coefficient of the bridge may be neglected, as it is too small to be appreciable within the limits of the work under consideration. The temperature coefficient of the material in test, however, must always be considered, *i.e.*, it must be decided whether it should be allowed for or not; in the former case make the proper allowance. Apparent disagreement between different departments frequently arises which on investigation will often be found to be due to a disregard of the temperature coefficient of the apparatus in question.

Should it be necessary to make a temperature correction for the bridge, great care must be taken to measure the temperature of the bridge coils correctly. A thermometer placed in the bridge box often does not nearly indicate the correct temperature of the coils, especially if the surrounding temperature is rapidly changing. The bridge should be kept in a nearly constant temperature and the indications of the thermometer in the box should remain substantially constant for an hour at least, better for two or three hours.

SLIDE WIRE BRIDGE

This is a modification of the Wheatstone Fridge, the slide wire forming two arms of the bridge and corresponding to the ratio arms in the Wheatstone.

Ohmmeter

The so called "Sage" Ohmmeter is essentially a slide wire bridge arranged for portable use where approximate values are sufficient.

This instrument is useful for special jobs and is found very convenient, especially on outside work, *i.e.*, where no fixed

bridge is available, such as in a power station, car barns, etc.
Its sensitiveness and consequently its degree of accuracy is
largely dependent on the hearing of the observer and the con-
dition of the dry cell batteries forming a part of the instrument

Fig. 12

WIRING DIAGRAM OF LOW RESISTANCE MEASURING OUTFIT

and supplying the necessary current for making a measurement.
A telephone receiver of the "watchcase" pattern is used on
this bridge in place of a galvanometer to determine when balance
is obtained.

Instructions already given regarding contacts and plugs apply. In addition the slide wire and "contact finger" should be given proper attention. The wire can be wiped off with the finger or a soft cloth when dirty. The contact finger may be cleaned with crocus cloth.

Under no circumstances use any emery or crocus on the slide wire as this will ruin the bridge. The bridge should be tested before starting on an outside job, to see if it is in working order, as the batteries deteriorate even when standing idle. Never leave the bridge connected, as metallic dirt or conducting material sometimes collects in the plug holes which may short circuit and spoil the battery if the receiver switch is not in working order, as occasionally happens. This switch should receive occasional attention.

The so called Weston ohmmeter is a low range voltmeter with a scale graduated to read in ohms. It will give fairly accurate results if the potential employed is constant and its value properly taken into account. The inverse ratio of deflections of the instrument without and with the unknown resistance connected in series is a measure of the resistance in ohms. It is further described under the Section on High Resistance by D.C. Voltmeter.

The "Evershed" ohmmeter is a true ohmmeter, because the scale readings are directly given in ohms and are independent of the current or voltages used. This outfit is not to be discussed here as its use has not been adopted. It is a valuable device for certain purposes; for further information refer to the makers or agents.

A comparison of the Evershed with the methods used in the Sage and Weston ohmmeters show why the two latter are not true ohmmeters. The Evershed apparatus is also used for high and insulation resistances.

LOW RESISTANCE MEASUREMENTS

Under this heading are included the "Thomson Bridge," sometimes called "Double" Bridge, and the "Drop Method," using an ammeter and voltmeter or their equivalents. See Fig. 12.

The Thomson Bridge

This is a modification of the Wheatstone Bridge and is suitable for use with low resistances, as its arrangement removes the objection to the former, *viz.*, the resistance of connections and plugs. It is also a modification of the "Drop Method" discussed later, but the accuracy of the results is not directly dependent on the value of the current employed. As this device is in the nature of a permanent fixture and a special operator is generally employed for its use, further explanation is not considered necessary.

The instructions, already given, in reference to contacts, plugs, slide wire, etc., also applies here. If a slide wire bridge

is not provided, with a roller the contact *must not be moved* until it is released from the wire. Failure to observe this will soon ruin the wire, especially if of small diameter.

Drop Method (Direct Current)

For this method current and potential measuring instruments of suitable ranges are required, *simultaneous readings* being taken on each; from these readings the resistance is calculated by

Ohm's Law $(R = \frac{E}{I})$.

The principal points for consideration are the general instructions relating to the location of the instruments, their influence on each other, etc., as given under the heading "General Precautions in Using Instruments," and also relating to the proper choice of the capacity of the instrument for a given purpose. The Current Standard must be connected in series with the resistance to be measured, and, where practicable, a suitable adjustable resistance for controlling the current. The volt standard is connected across the resistance to be measured, so as to measure its potential drop. A non-inductive resistance may be connected in series with the voltmeter to alter its sensitiveness if required. This resistance should have a current capacity equal to that of the voltmeter.

The instruments should be so chosen that the deflections obtained are reasonably large, in order to reduce the error of observation as much as possible. The current used should be sufficient to give a good deflection on the ammeter. It must not, however, be great enough to heat the resistance under test and thereby change its resistance. This point is very important and frequently overlooked; the greater the temperature coefficient of the material of the resistance the more important it becomes. If the current employed in making the measurement is not steady, two observers should take observations, one reading the ammeter and the other the voltmeter. Simultaneous readings should be taken, each reading being repeated several times, the average reading being used to determine the final result. Neglect in considering the ratio of the resistance of the voltmeter used to that of the apparatus under test sometimes introduces errors. If the ratio is large (2000 or more) the law of divided circuits can be neglected and the result obtained from Ohm's Law as previously stated. If the ratio is small, allowance must be made, since a part of the current is shunted through the voltmeter, which is also measured by the ammeter.

To illustrate this point take the following example, as per Fig. 13.

By Ohm's Law, $R_x = \frac{.5}{100} = .005$ ohms. If allowance is made for the current shunted through V the true value for R_x will be altered $R_x \times .005$ times or .02 per cent. error, which is too small to

consider. This is found as follows: The current U_v through V is equal to $\frac{E}{r_y}$ or $\frac{.5}{100} = .005$ amps. Now $i_x = I - i_v$ or $100 - .005$ $= 99.995$. Since the value of R_x is equal to $\frac{I}{i_x} R_x = \frac{.5}{99.995} =$ .0050025 the value as given above. Again suppose for illustration $r_v = 1$. Then following the same reasoning, we have $R_x = .005025$ or .05 per cent. error which is too large to be neglected.

HIGH RESISTANCE MEASUREMENTS

Under this heading "High Resistance D.C. Voltmeter," and "Insulation Resistance Measuring Sets," are considered.

D.C. Voltmeter

A high resistance instrument (50,000 ohms or more) is generally used for high resistance measurements. For lower

$r_v = 100$ or 1
Reading on $V = .5$ volt
i_v
$I = 100$ amp
i_x R_X
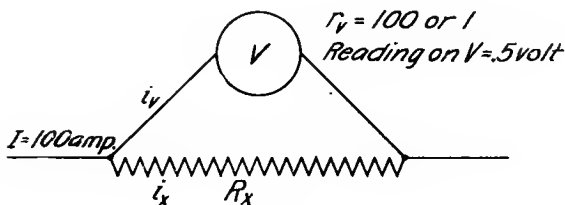
Fig. 13

resistances, lower voltages and a lower resistance voltmeter may be used. The Weston ohmmeter belongs to this class. In these cases on the voltmeter, deflection is directly proportional to the current flowing through it, and inversely proportional to the resistance of the circuit with constant potential across it.

A constant potential of about 500 volts is usually employed. This voltage reading is determined by connecting the terminals of the supply directly to the voltmeter. The resistance to be measured is then connected in series with the voltmeter and a second reading made and noted. The resistance X is then given by the formula $\frac{R_m}{R_m + X} = \frac{D_m}{V}$; where $R_m + X = \frac{VR_m}{D_m}$

R_m = resistance of the voltmeter used; D_m the deflection of the voltmeter with resistance in series; V the voltage of the supply when taking reading D_m, and X is the resistance sought.

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If the value of X is large relative to R_m it is not generally necessary to subtract R_m to get X, and this is not usually done.

In making these measurements do not attempt to use a voltmeter which reads lower than the voltage of supply, as in case the resistance is omitted the instrument is likely to burn out. Do not try to get results by this method unless the supply is steady and constant or a second instrument is available connected directly to the line all the time with a second observer for taking simultaneous readings. When two instruments are used do not get their resistance values mixed; the resistance of the instrument reading the voltage is immaterial.

A suitable reflecting galvanometer calibrated to read in volts may be used in place of the voltmeter. The method and calculations are the same as described above.

INSULATION RESISTANCE TESTING SETS

The principle of operation is similar to that of the D.C. voltmeter, a shunt box being added to increase the range of the galvanometer which is used in place of the voltmeter in the other method.

The galvanometer constant $K = \dfrac{D \times S \times R \times C_2}{10^6 \times C}$ and the resistance $= \dfrac{K_2}{D_2 S}$ where D = deflection of galvanometer when taking constant; D_2 when making observation; S = multiplying factor for shunt; R = resistance in series when taking constant; C and C_2 = number of cells used when taking constant and observation respectively.

Complete instructions are furnished with the portable outfit when sent out. The permanent outfits work on the same principle and are generally installed with other testing apparatus where a special operator is available.

The following points should be mentioned. The various parts of the entire outfit, including the connecting wires (both internal and external), must be properly insulated from each other and from earth to prevent leakages. If this is not done, leakage currents may pass through the galvanometer and not through the resistance being measured, thus falsifying the results.

If the resistance being measured lies between the earth and some conductor, as is the case with a lead covered cable, one side of the galvanometer should be connected directly to earth, taking precaution to insulate the rest of the circuit well. To form an earth, a bare wire may be used grounded to earth, to which one side of the galvanometer is connected. With this arrangement, if any leakage occurs, the leakage current is shunted by the galvanometer and does not affect the readings. Where possible, leakage should be eliminated, but reasonably correct results can be obtained by testing, changing over the connections and averaging the results.

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When making insulation tests on cables tests should be made for earth currents. To do this, disconnect the battery and short circuit the terminals to which the battery was connected. Then, connect to ground and to line and observe the galvanometer deflection. If there is no deflection no leakage currents exist, if there is a deflection of constant direction and amount a dead resistance equal to the internal resistance of the battery can be substituted in place of the short circuiting wire and the amount and direction of the galvanometer deflection can again be observed. This deflection is added or subtracted from the deflection obtained when making the test, before dividing into the constant. Since the battery resistance is small compared to the resistance under test, it can usually be neglected and the deflection used as obtained with the short circuiting wire. If the earth currents are very appreciable or unsteady in amount or direction the test should not be taken until the conditions are more suitable.

Chloride of Silver Dry Cell Batteries are generally used to supply the current for these resistance measurements.

These cells are very quickly ruined by short-circuiting or using them on too low a resistance. The cells should never have less than 5000 ohms per cell connected in series with the circuit connected to them.

Never put wires or other material into the battery covers, which could short circuit the cells. The space between the covers and cell tops may seem to be a convenient place to carry spare wire but this practice causes trouble. Abrasion of the insulation on the lead wires supplied with the batteries may short circuit the cells, and must not be allowed.

The cells should be tested before using to see that they are in good order (giving about .8 to 1 volt). In any case the e.m.fs. of the two cells must be sufficient to allow the operator to get correct results. The resistance of the voltmeter used should be at least 5000 ohms, or if several cells in series are tested at once, the voltmeter resistance in ohms must be at least 5000 times the number of cells tested in series.

It frequently happens that some of the cells in a battery give only a fraction of their proper voltage; in such cases the voltage of each individual cell must be considered when making a test, and the total voltage must not be estimated merely from the number of cells in use.

Wherever possible, cells below normal voltage should be rejected and replaced by new cells.

When an outfit is permanently installed, the No. 4 Columbia Dry cell is satisfactory for insulation work if a considerable number of tests have to be made or heavy currents are required, as they will withstand rough usage. As the voltage of this cell is higher (being about $1\frac{1}{2}$ volts) than that of Chloride of Silver cell, fewer are required.

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Measurement of Electromotive Force

The primary standard of e.m.f. for the Standardizing Laboratory is the Clark Cell. This is made according to the United States specifications prepared by the National Bureau of Standards at Washington. Its e.m.f. is 1.434 volts at 15° C. It has, however, a large temperature coefficient, and for practical work is replaced by the Weston standard cell, whose e.m.f. is determined at intervals by comparison with the Clark cells. To compare an e.m.f. directly with the standard, the potentiometer is used.

In the potentiometer the e.m.f. of the standard cell is balanced against the drop of potential caused by passing current through the potentiometer shunt from a storage cell. This shunt consists of a series of adjusted resistance coils and a slide wire marked to scale. By setting the contacts of the circuit containing the galvanometer and the standard cell at scale points indicating the exact voltage of the standard cell, and adjusting the storage battery until the circuit balances and the galvanometer reads zero, the potentiometer becomes direct reading. Any external voltage not exceeding 1.5 volts may then be read by balancing it against the drop across a suitable part of the potentiometer shunt. For extreme accuracy a small correction is made to allow for known variations in the resistance of the various sections of the slide wire. To measure higher voltages a multiplier is used which will reduce 15, 150 or 750 volts to the 1.5 volts required for the potentiometer.

For a working standard of direct voltage a G.E. laboratory standard voltmeter is used, and for alternating voltage a Weston standard voltmeter. These are frequently calibrated to the primary standard. In the case of the A.C. instrument, reversed readings are made in calibration, to insure agreement between A.C. readings and D.C. calibrations. The instruments to be calibrated are compared with the working standards, by means of a system of multipliers which give the necessary range to the working standard.

For the measurement of direct voltages, two kinds of voltmeters are used, Weston, and Thomson D.P. These give a range from 1 to 750 volts with full scale reading. Both operate by the torque produced on a movable coil carrying current located in the field of a permanent magnet. A very powerful stray field may, however, partially demagnetize or cross magnetize the instrument and permanently change its calibration. Some voltmeters are shielded and some are not. The non-shielded meters are easily affected by stray fields. Weston instruments are ironclad and D.P. are not easily affected. Both types are also made as millivoltmeters with low resistances, reading from .200 millivolts up.

Never connect any instrument marked "Millivoltmeter" or "Special Meter" across higher voltage than it reads otherwise the instrument will burn out. To measure voltage higher than the capacity of the instrument a multiplier may be placed in

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series with it. Then if E is the corrected reading of the voltmeter, V the voltage to be measured, R_v and R_m the resistances of the voltmeter and of the multiplier,

$$V = E \times \frac{R_v + R_m}{R_v}$$

or, two voltmeters may be placed in series and careful simultaneous readings taken; the sum of the two corrected readings is the voltage to be measured. One of the two voltmeters may be considered as a multiplier for the other; then if E_1 and E_2 are the corrected readings on the two instruments at one point, and E is the corrected reading on the first instrument at any other point,

$$V = E \times \frac{E_1 + E_2}{E_1}$$

For all D.C. instruments, the Standardizing Laboratory gives a constant K, such that if $V =$ corrected voltage and $E =$ reading of the instrument,
$$V = K \times E$$

From this $E = \dfrac{V}{K}$

Therefore, to obtain the reading on the instrument which corresponds to the voltage required, divide the correct voltage by the constant of the instrument. Since these constants are never far from unity, the equation

$$E = (2 - K) \times V = V + (1 - K) \times V$$

is nearly true. This is the most convenient method for getting the proper reading.

Illustration: 110 volts required $K = 1.003$

$$\begin{aligned} E &= V + (1 - K) \times V \\ &= 110 + (1 - 1.003) \times 110 \\ &= 110 - .003 \times 110 \\ &= 109.67 \end{aligned}$$

Most instruments used in the test are provided with a mirror under the needle. To eliminate parallax and obtain the correct reading, sight the needle when it exactly covers its mirror image, then without altering the position, read the intersection of the needle with the inner scale circle. It should be remembered that while the scale on most D.C. instruments is equally divided, so that the errors of observation are nearly the same in actual amount in all parts of the scale, the percentage error varies inversely with the deflection. Hence when accuracy is required, the instrument must not be read at a low point on the scale.

Before using any instrument, it should be carefully inspected to determine whether the needle is free and rests at zero. No instrument which sticks at any part of the scale should be used nor should an instrument be used which has a zero error. D.C. voltmeters should be disconnected from field circuits while the field switch is being opened, because of the inductive kick, which frequently bends the needle. They should also be disconnected from synchronous motor or rotary fields, while the

machines are starting from the A.C. side because of the high alternating voltage developed by transformer action in the field windings during starting. This voltage will sometimes puncture or burn out a voltmeter.

A voltmeter should always be connected through a double-pole switch, and should be kept out of circuit when not in use, as its readings may change with long continued heating. The cover glass should never be rubbed before reading on account of the electrostatic effect on the needle. If a cover glass shows electrification, it may be discharged by moistening it with the breath. No moisture should be allowed to reach the inside of the instrument.

Two types of Thomson voltmeters are generally used for the measurement of alternating voltage,—Type P and Type P3. The P3 instrument may also be used on direct current voltage without sensible error, but the P instrument must not be so used for accurate work unless nearly full scale readings are taken on instruments with a range of from 15 to 750 volts full scale reading.

On account of the spreading of the scale through the upper part of the range of the instrument, A.C. instruments cannot be used with accuracy as low on the scale as D.C. instruments. In general a P instrument should not be used below $\frac{1}{3}$ its maximum reading. The P instruments, containing no permanent magnets or shields, are also sensitive to the action of stray fields, especially if this field alternates at the same frequency as the voltage applied to the instrument. They should, therefore, be kept away from masses of iron and from cables carrying heavy currents, and should be placed at least two feet from other instruments. The P3 instruments are much less sensitive to stray fields, and may be placed within two inches of one another without sensible error.

Cables carrying heavy currents, whether D.C. or A.C., should be kept close together. They must never pass on opposite sides of a machine standing on an iron floor. If an instrument reads alike in four positions 90° apart, it is unaffected by stray fields. Protection from stray fields is sometimes obtained by placing the instrument in an open topped iron box. This is an efficient protection as far as the stray fields are concerned, but the readings of the instrument may be slightly changed by the proximity of the iron to the field of the instrument.

For all A.C. instruments the Standardizing Laboratory furnishes curves of calibration, in which the instrument reading is plotted against the reading of a correct standard. These curves should be used to correct readings and to determine the proper reading for any voltage required.

Potential Transformers

For most commercial alternating voltages a 130 or 150 volt voltmeter is used in connection with a potential transformer. The following transformer voltages are in common use:

Oil insulated, iron case.

Primary volts	Secondary volts
13200	110
11000	110
6600	110
5500	110

Dry insulated, wooden box.

550/1100	110/220
1100/2200	110/220

All these transformers are designed for use from 25 cycles upward. They are calibrated with a load of a single instrument, and should not be loaded with more than two instruments nor used at 25 cycles above the normal rated transformer voltage of the particular connection employed if accurate results are desired. When used below 25 cycles, the voltage at which reasonable accuracy may be secured varies directly with the frequency. The transformer primary must be connected to the lines and the secondary to the instruments.

In the wooden box type there are four primary and four secondary terminals, from which three voltage ratios may be obtained; *viz.*, series multiple, series series, or multiple series connection. For series connection, the two inner terminals are connected and the lines or instrument leads are connected to the two outer terminals. For multiple connection, the two terminals on one side are connected to one line or lead and the two on the opposite side are connected to the other. The cases of the iron potential transformers should always be grounded. No changes should ever be made in connections with the high potential on.

Care should be taken that voltage leads are always connected to the points between which the difference of potential is to be read. Thus, in reading volts across the armature on a compound wound D.C. machine, the leads should be attached to the brushes, while in reading volts across the machine they should be attached to the outer end of the series field and the brush ring of opposite polarity. In any circuit where voltage drop is measured, the resistance of an extra connection in the main current circuit included between the voltmeter contacts is often sufficient to cause serious error. Only the voltmeter current should flow through the voltmeter leads.

Measurement of Current

The primary standard of current is the silver voltameter, which is used for comparison occasionally. The practical standard used is a set of standard resistances very accurately calibrated. The voltage drop across these resistances is measured by the potentiometer, the result being a direct measure of current. Slight corrections are made for the slide wire and the resistance of the external shunt.

A special standard millivoltmeter with a set of shunts attached constitutes the working standard of direct current. The working standards for alternating current include a series of Kelvin balances covering a wide range of currents. The working

standards are calibrated from the potentiometer, reversed readings being used for the balances. The portable instruments are compared with the working standards.

The D.C. ammeters used in the test are Weston or Thomson Type D.P. instruments. They range from .150 ampere to 300 amperes. For reading larger currents, a shunt is used in connection with a millivoltmeter. The following shunts are used: the 500, 1000 and 2000 ampere, air cooled. Manganin shunts may be used with any standard Weston Millivoltmeter, which are designed for a .400 volt drop at ratio amperes, giving a full scale reading.

The 5000 ampere air cooled Thomson shunts give .060 volt drop, and must be used with an instrument designed for this reading. This combination has an appreciable temperature coefficient, and should not be used for accurate measurements without special instructions from the Standardizing Laboratory. There are also several 5000 ampere oil cooled shunts having .200 volt drop, which must be used with an instrument of this range. Small station shunts with .200 volt special meters are also used for the measurement of current in low resistance circuits, such as the current through commutating pole fields.

In reading a special meter attached to a shunt, assume the end of the scale to represent the rated amperes of the shunt, and read the result accordingly. To correct for instrument error, multiply by the instrument constant. To correct for the shunt error, multiply by $\frac{E}{IR}$, where E = rated volts drop of the shunt, I = rated current of the shunt, and R = actual resistance of the shunt. This correction is very small, and may usually be neglected.

For measuring current beyond the capacities of the instruments at hand, two ammeters may be placed in multiple; but both instruments must be read simultaneously at every point. If two shunts are used in multiple, special meters must be connected to each and readings taken on both.

For the measurement of alternating current, Types P and P3 are used. The general statements as to voltmeters apply equally to ammeters of the same type. The ammeters are somewhat more likely to produce stray fields, especially the high current instruments. Ammeters should be protected by a short circuiting switch, which is kept closed except when reading.

The usual method of measuring high alternating currents is by using current transformers in connection with low reading ammeters. The standard commercial G.E. transformers have a 5 ampere secondary. Some of these are in use as permanent apparatus in the test. Portable wooden boxed transformers of 500:50 and 5000:100 amperes capacity are also in use. Current transformers have a core and windings like a low voltage, high current power transformer, but are insulated to stand considerable voltages, except when of the wooden box type. The ratio given by the Laboratory for a point is accurate at that

point, but the ratio varies somewhat for lower or higher currents. The secondary should not carry more current than that required by two instruments. The secondary circuit of a current transformer must never be open while current flows through the primary. If this precaution is not taken, there is danger of the transformer overheating and thereby breaking down the insulation. There is also danger to anyone handling the secondary, owing to its high voltage. All these transformers can be used on circuits operating at 25 to 125 cycles.

To measure the currents in a three-phase circuit, two equally rated current transformers and three ammeters are necessary. The primaries of the two transformers are placed in two of the lines; the secondaries are connected with like polarities together (straight connection); a common connection is added so as to short both secondaries. One ammeter is placed in each separate transformer secondary circuit; the third ammeter goes in the common line, and reads the current in the third phase.

Measurement of Power

There is no primary standard of electrical power in practical use. Wattmeters are used which are calibrated from the standards of current and electromotive force. For D.C. calibration, 100 volts, as given by a laboratory standard voltmeter, is applied to the potential circuit of the wattmeter, and current measured on a standard ammeter is sent through wattmeter current circuit. The product of the volts and amperes gives the true watts, which are plotted against the readings of the instrument. For A.C. calibration at unity power factor, readings are taken direct and reversed and the average reading is used. If a calibration at low power factor is required, the phase position of the voltage on the instrument is regulated by means of a phase shifter while the readings are compared with those of a calibrated dynamometer.

P and P3 instruments are used on the test. Their potential circuits are for 150 volts, with current circuits ranging from 1 to 200 amperes. The full scale readings range from 150 to 20,000 watts. The P instruments are the more sensitive to stray fields.

Never apply more than the rated voltage to the potential circuit. The current circuit will carry up to three times the rated amperes for a short time. The accuracy of the wattmeter depends but slightly on the ratio of current and potential applied. To correct a reading of a wattmeter, compare with the calibration curve. Current and potential transformers may be used with wattmeters where current or potential is larger than rated. If R_w is the reading of the wattmeter, C the ratio of the current transformer, and P the ratio of the potential transformer,

$$\text{True watts} = P \times C \times R_w$$

When wattmeters are used with current or potential transformers, the potential circuit, current circuit, and case of the wattmeter should be connected together with a light fuse wire, to prevent differences of potential between the coils and case.

If a wattmeter potential circuit is not absolutely noninductive, the current in it will have a slight phase displacement relative to the voltage across the wattmeter terminals. This is equivalent to a change in the phase angle between the voltage and current of the main circuit as read on the wattmeter. Hence, wattmeters are subject to an error, from which ammeters and voltmeters are free. If a current and a potential transformer are used, there is usually a further phase difference between primary and secondary current in the former, and between primary and secondary voltage in the latter. The result of these three angular changes is a change in the phase relation in the watt-meter. The total change rarely exceeds 2°, and is frequently less than 30'. At or near unity power factor its effect on the reading is inappreciable; but at a very low power factor large errors may result. Where special accuracy on wattmeter work on low power factor is required, the matter should be referred to the laboratory.

In measuring the watts in a two-phase circuit, each phase should be considered as a separate single-phase circuit. The sum of the readings on two wattmeters gives the total watts.

In a three-phase circuit two wattmeters should be used. The current coils should be placed in two of the phases and each potential coil connected from that phase in which its current circuit is placed, to the third phase. The algebraic sum of the wattmeter readings gives the total watts. The higher reading wattmeter is always positive; the lower reading is positive if the power factor is above .5, negative if it is below .5. To determine by test whether the reading is positive or negative, open the phase to which the wattmeter in question is not connected. This leaves a single-phase circuit on the wattmeter; if the wattmeter still reads forward, it will give positive values on the three-phase connection. If it reads backwards, it gives negative readings on three-phase.

The watts in a three-phase circuit may also be read with three wattmeters. In this case a Y-box consisting of three equal resistances starting from a common or Y point is connected to the three lines. The Y point then becomes a neutral point for the three lines. A wattmeter is connected in each line, and its potential circuit is connected from its own line to the Y point.

When reading a small power at a moderately high voltage on a wattmeter, the wattmeter reading may be affected by the losses in the instrument itself. If the current flowing in the voltage circuit of the wattmeter passes also through the current coil, the wattmeter reads the losses in its potential coil. If a voltmeter is similarly connected, the wattmeter reads its losses also. If E is the applied voltage and R the resistance of the loss circuit, then, since the circuit is practically noninductive, $\text{loss} = \dfrac{E^2}{R}$.

If the wattmeter and voltmeter are so connected as to prevent the current in the potential circuits from flowing through the current coil, the wattmeter reads the losses in its current

coil, and the voltmeter reads the drop through the wattmeter current coil in addition to the voltage across the load. These errors are nearly always negligible. If the wattmeter reads the losses in potential circuits, a measure of the amount of the losses may be had by reading the wattmeter, after opening the load circuit so as to leave all instruments connected to the main lines. This is called reading stray power, and is a good check for leakage losses.

Measurement of Power Factor

The power factor of a single-phase circuit $= \dfrac{\text{Watts}}{\text{volts} \times \text{amps.}}$
There is no single-phase power factor meter which is independent of frequency through any considerable range. The power factor is therefore usually obtained by the use of voltmeter, ammeter and wattmeter.

In a balanced three-phase circuit, the power factor may be obtained from the two wattmeter readings. If a is the phase angle, the power factor $= cos\ a$, and R is the ratio of the smaller to the greater wattmeter reading,

$$Tan\ a = \frac{1-R}{1+R}\sqrt{3}$$

The principle of the G.E. balanced three-phase power factor meter uses this fact. The elements of two wattmeters are so combined into one instrument that the position of the pointer depends on the ratio of the watts. The instrument is quite accurate, and practically independent of frequency.

The volt amperes in a balanced three-phase circuit are equal to the product of the amperes per line, the volts between lines, and the square root of three.

STEAM FLOW METERS

The following is a description of flow meters and includes the methods of installation and operation of the various types of meter.

Principle of the Meters

A plug, containing two sets of funnel openings, is screwed into the main, the flow in which is to be measured. The pressures existing in these openings are transmitted to the surfaces of the working fluid in the meter itself and cause differences in the surface levels. Mercury is employed as a working fluid when measuring steam flow, while water may be used in special cases. These differences in level, which vary with the flow, are utilized for the operation of the meter.

Installation of Funnel Plugs

The funnel plugs can be installed in vertical or horizontal pipes. Figure 14 shows the positions of the funnel plugs for

either vertical or horizontal mains, and also a convenient form of gauge for measuring the inner diameter of the pipe. The funnel type and the size of pipe for which each plug is designed are stamped upon the head of the plug. The arrow at the same place should point in the direction of flow.

The entire system of piping and valves must have no leaks. The water columns in the meter piping should contain no air, as unequal heads in the two pipes affect the accuracy of the calibration.

The meters are tested after the finishes are applied and the Testing Department is responsible for injury before shipment.

Arrow on Head of Plug must Point in the Direction of Flow

Horizontal Pipe

Pipe Diam.

Gauge for Measuring Inside Pipe Diameter.

Arrow on Head of Plug must Point in the Direction of Flow

Vertical Pipe
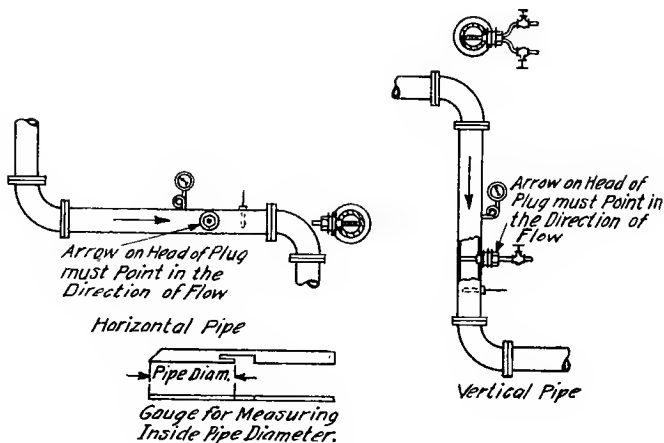
Fig. 14

Care should be taken not to spill the mercury when filling a meter, as it corrodes the parts containing brass or aluminum.

Type I, Form B

Meter Adjustments

Remove the plugs P (Fig. 15) at the top of the meter and pour in mercury with the tubes in approximately a vertical position, until each leg is about half full.

Tilt the meter sideways so that most of the mercury is in one leg.

Fill with water up to the plugs P.

Remove any air bubbles by inserting a broom straw. Do not use wire for this purpose.

Insert the plugs P.

Operation of the Meter

Set the meter in a horizontal position by means of the level and take care that the piping to the funnel plug does not throw it out of level.

These pipes should be connected in accordance with Fig. 14, and can be of any desired length.

Care should be taken that no air trap is formed in the piping between the meter and the funnel plug.

To Check Zero on the Meter

With the valve C open and the valves L and T closed, remove the plugs A and B at the top of the piping
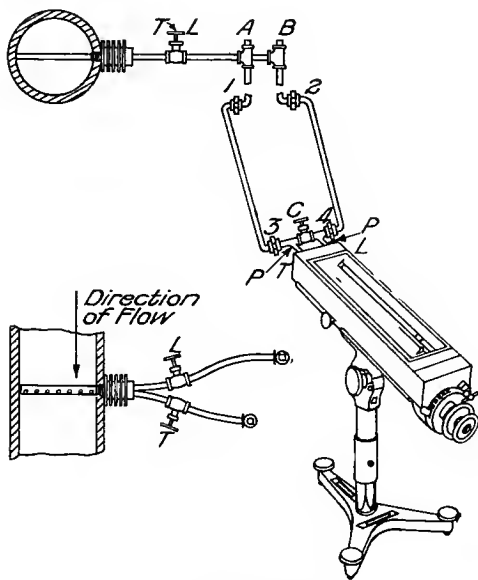
Fig. 15
FLOW METER

Pour in water at A and B until the piping is full.

Close the valve C.

Set the sleeves surrounding the glass tubes so that their centers are opposite the ends of the mercury columns.

The pointer should now indicate zero flow on the cylinder. If it does not read at zero there may be air in the piping or the meter may not be set level or the glass tubes may not be straight.

Always open the valve C and insert the plugs A and B before opening the valves L and T.

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To Cut in the Meter

Open the valve C.
Open the valves L and T.
Close the valve C.

Caution

Never open or close either valve L or T unless the valve C is open.

To Read the Meter

Release the clamp at the bottom of the meter.

Loosen the set screw inside the inner handwheel on the shaft. Bring this set screw opposite either of the numbers 1, 2 or 3 (on the handwheel), depending on the part of the superheat scale to be made accessible. Then tighten the set screw.

Rotate the inside scale disc until the value corresponding to the measured inner diameter of the steam main is opposite the corresponding number, 1, 2 or 3 (on the lower head of the meter).

Observe the pressure and superheat of the steam.

Rotate the inside handwheel until the values corresponding to this pressure and superheat are opposite each other on their respective scales.

Tighten the clamp.

Rotate the outer wheel at the bottom of the meter until the center of the sleeve surrounding the right hand tube is opposite the end of the mercury column.

Set the sleeve on the left hand glass tube opposite the end of the mercury column.

The reading now indicated by the pointer, multiplied by the constant K, and by the pipe area in sq. in. will give the flow of steam in lbs. per hour.

This constant K is shown at the small hole at the top of the post supporting the meter.

To Cut Out the Meter

Open the valve C.
Close the valves L and T.

Glass Tubes

These tubes should be occasionally tested with a straight edge to be sure that they have not warped.

To replace warped or broken glass tubes, remove the plugs P at the top of the meter. Loosen the stuffing boxes and pull the tube out through the upper head of the meter. Insert the new tube taking care to replace the rubber packings, the glands and the tubes in the correct order.

To Change the Angle of the Meter

Loosen the unions 1, 2, 3 and 4.
Set the meter at the desired angle.
Tighten the unions.

Mercury

Use only clean mercury in the meter. To clean mercury, treat it with dilute nitric acid and wash with running water.

Caution

If the funnel plug is inserted in the main near a flanged joint, do not allow the gasket to extend inside the pipe.

Setting Correction Scales

Set 6 on the pipe diameter scale opposite the number 1, 2 or 3 on the lower head of the meter. Set the set screw inside the inner handwheel opposite the corresponding number 1, 2 or 3 (on the handwheel). Set 100 on the pressure scale opposite 5 on the superheat scale. The pointer should now register at the point marked on the cylindrical chart at a distance of 2 inches above the zero line.

INDICATING AIR METER

Type I, Form F

Meter Adjustments

The meter should be set in a horizontal position by means of a level and care should be taken that the piping to the meter does not throw it out of level.

Care should be taken that no water trap is formed in the piping between the meter and the funnel plug excepting at the place where the drip chambers are inserted.

Location of Meter

The meter may be located at any desired distance above or below the point at which the funnel plug is inserted. If the meter is above this point the piping must have an upward slope all the way from the drip chambers to the meter. If, on the other hand, the meter is below the plug the piping must slope downward toward the meter.

To Check Zero on the Meter

With the funnel valves L and T closed, open the crossover valve X, shown in Fig. 16.

Attach the float and the counterweight to the cords furnished with the meter. Remove the cover plate at the top of the meter casting. Hook the cords over the drums in their proper positions, the float hanging from the larger drum.

Fill the meter with water until it rises to a height of approximately $7\frac{5}{8}$ inches below the top of the casting. See the distance V in Fig. 16. If too much water is poured in, remove the plug near the bottom of the casting and allow water to run out until it stops flowing.

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Rotate the dial so that the needle reads zero flow.

Insert the plug and replace the cover before opening either funnel valve.

To Cut in the Meter

With the crossover valve X open, open the funnel valves L and T. Then close the crossover valve.
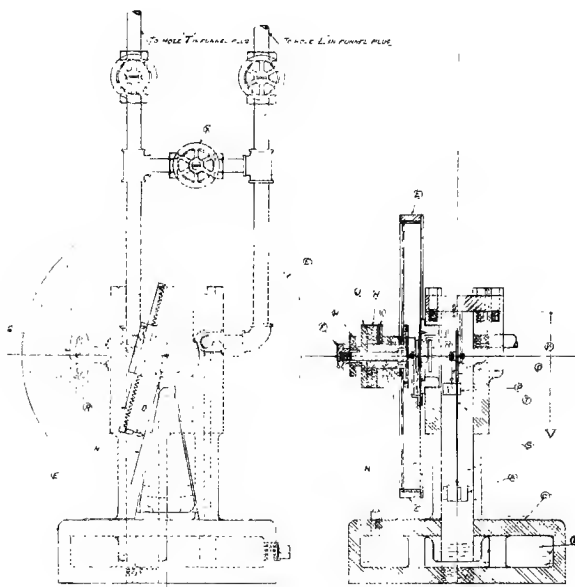

Fig. 16
FLOW METER

Caution

Never open or close either funnel valve L or T unless the crossover valve X is open.

To Read the Meter

Set the actual measured diameter of the air pipe, on the scale H, opposite the point O.

Set the observed air pressure, on the scale J, opposite the actual temperature in the main on scale H.

Tighten the set screw F and rotate the wheel W until the pointer D is directly over the needle.

The pointer will now read the flow of free air in cubic feet per minute at a temperature of 70° F. for one sq. in. of pipe area. Multiply the reading by the pipe area to obtain the total rate of flow.

To Cut Out the Meter

Open the crossover valve X and close the funnel valves L and T.
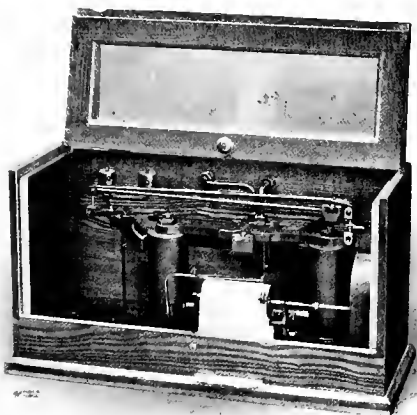
Fig. 17
CURVE DRAWING STEAM FLOW METER.

Drip Chambers

This meter is furnished with drip chambers in the piping to the funnel plug. These chambers should be located between the funnel valve and the funnel plug, one in each pipe.

Caution

Never blow out these drip chambers unless both funnel valves L and T are closed.

If the funnel plug is inserted in the main near a flanged joint, do not allow the gasket to extend inside the pipe.

Setting Correction Scale

The settings for the correction scales depend upon the range of dial and pressure scales employed on any particular meter.

CURVE DRAWING STEAM METER

Type R, Form D

Meter Adjustments

Remove the plugs P at the tops of the mercury cups, Figs. 17 and 18, and pour in 2.5 lbs. of mercury with the cups in approximately a vertical position.

Fill with water through the top of each cup until water flows out of the pipes extending through the meter casing.

Close the outside ends of these small pipes with the finger while replacing the small plugs.

Installation of the Meter

Set the meter in a horizontal position by means of a level on the floor of the casing and take care that the piping to the funnel plug does not throw the meter out of level.
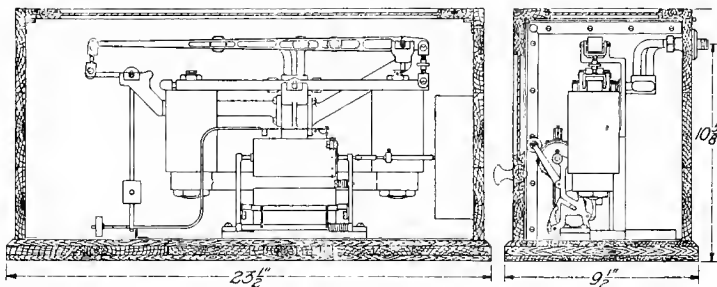
Fig. 18
CURVE DRAWING STEAM FLOW METER.

These pipes should be connected in accordance with Fig. 14, and can be of any desired length.

Caution

Care should be taken that no air trap is formed in the piping between the meter and the funnel plug.

To Check Zero on the Meter

With the valve C open and the valves L and T closed, remove the plugs A and B at the top of the reservoirs near the funnel plug.

Pour in water at A and B until the piping and reservoirs are full.

Close the valve C.

The pen should now indicate at the zero flow line on the chart. If it does not register at zero, adjust the adjusting screw until it does.

Always open the valve C and insert the plugs A and B before opening the valves L and T.

To Cut in the Meter

Open the valve C.
Open the valves L and T.
Close the valve C.

Caution

Never open or close either funnel valve L or T unless the valve C is open.

Setting of the Correction Weight

The position in which the correction weight should be set depends upon the range of pressure and flow for which the meter is intended.

The meter will now record the true rated flow of steam in lbs. per hour provided the proper record chart is used.

To Cut Out the Meter

Open the valve C.
Close the valves L and T.

Mercury

Use only clean mercury in the meter. To clean mercury, treat it with dilute nitric acid and wash with running water.

Caution

If the funnel plug is inserted in the main near a flanged joint, do not allow the gasket to extend inside the pipe.

FREQUENCY INDICATORS—REED TYPE

Frequency Indicators of the reed type are based on the following principle: A reed having a definite natural period of vibration will be thrown into more or less violent vibration when acted upon by an impulse of the same frequency. Hence, in the construction of these meters a number of reeds are arranged which will correspond to various frequencies. These reeds are made up of magnetic metal. An iron cored electromagnet is located close to this line of reeds. When the magnet is excited with an alternating or pulsating current, magnetic impulses act upon all reeds in the scale and throw into violent vibration that reed whose natural period corresponds to the period of the impulse. The scale reading gives the natural period of vibration of the reed corresponding, or some multiple of that period.

The type of frequency indicator which is employed in the Testing Department carries two scales, one reading from 45 to 60 cycles per second, the other from 60 to 90 cycles per second.

If a frequency has to be kept constant or read on an alternating current circuit, the meter is connected across the circuit. A switch is located on the end of the meter case with 7 contact points. By turning this switch a varying resistance is introduced in series with the magnet coil. Consequently the amplitude of vibration of the reeds may be controlled and adjusted to that sufficient for a careful observation. At the same end of the case are located two thumb screws actuating two permanent magnets within the case. When these permanent magnets are rotated so that they act upon the reed they damp out one-half of each cycle, and consequently change the scale indication for a given reading by one-half. In other words, when these magnets are in operation the meter will read one-half the frequency impressed at its terminals.

These meters can be used in place of the ordinary centrifugal or liquid tachometer. They possess important advantages over tachometers of other types since they may be located at the testing table so that meter readings and speed control can be done by one man. They can be read more accurately and are not influenced by the direction of rotation. The calibration is also very permanent.

In order to use meters to read speed on a direct current machine, or on machines which are unexcited, a small direct current interrupter has been placed on the spindles of centrifugal tachometers. This interrupter is provided with binding posts which must be connected in series with the frequency meter and a 125 volt circuit. The interrupter may be used with a single or double contact point. In case it is used with a single contact point, the frequency indication on the meter corresponding to a given speed should be calculated on the assumption that the interrupter is a four-pole alternator. When the double contact combination is used, the interrupter must be considered as an eight-pole alternator.

It is not safe to use these frequency meters for measuring the speed of a machine under test when it is first started, since they cannot always distinguish between 20 cycles or 40 cycles, in consequence of the fact that both a 20 cycle and a 40 cycle reed will vibrate at 20 or 40 cycles. Hence, the speed should be roughly set to that desired, by reading the tachometer dial, after which it can be exactly adjusted by the frequency meter. Due to the many advantages of these instruments they should be employed wherever possible, in place of the ordinary tachometer for testing work.

STATIONARY TORQUE RECORDER

Some alternating current motors have a starting torque which varies considerably according to the position of the rotor at starting. In many cases, therefore, the variation of starting torque at different rotor positions has to be measured.

This information can be most satisfactorily obtained by using a graphic recording torque meter. Fig. 19 is a sketch of an

instrument that is successfully employed in the Testing Department for quickly and accurately obtaining this torque. In this sketch G represents a form of lever commonly used. It is clamped around the pulley or the shaft of the motor under test. A wooden disc H is provided, of triangular cross section radially. On its conical surface a series of $\frac{1}{8}$ in. grooves are located to accommodate the cord K. This cord rotates the drum E of a steam engine indicator on which a record of the variations in the torque is traced. The post A supporting the indicator is hollow,
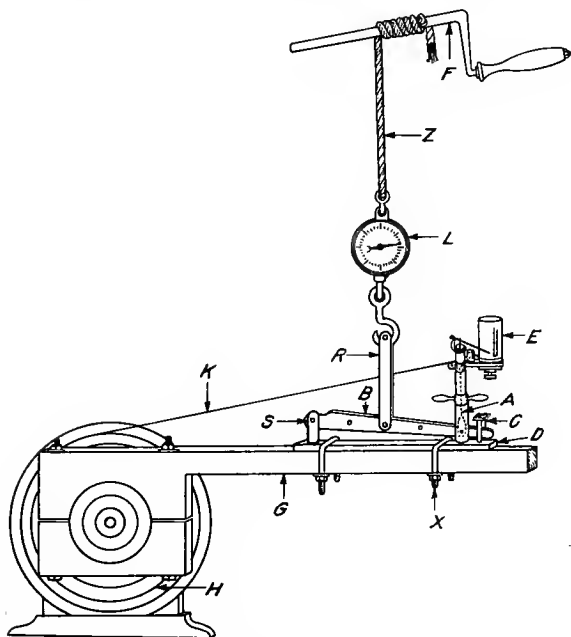
Fig. 19
STATIONARY TORQUE RECORDER

and a rod connected to the lever B at the lower end and bearing against the spring of the indicator, transmits any movement of B to the spring, and in turn to the pencil bearing upon the drum. The lever B is provided with a number of holes so that it can be attached to the stirrup R at various distances from the fulcrum S, by which means different leverages can be secured. By this adjustment, and by clamping the complete apparatus to the lever arm at different distances from the motor shaft, the maximum travel of the recording pencil on the drum can be

kept within the limits normal for the indicator spring used
The shaft and crank F are supported at right angles to the lever
B by an iron pipe frame not shown in the sketch. The spring
balance L is used only in calibrating the apparatus and is then
disconnected and the rope Z connected directly to the stirrup R
The calibration of this instrument should be made as follows

With no tension on the rope, pull the cord K and revolve the
drum E, thus recording the zero line on the paper record. Raise
the outer end of the lever above the horizontal position and with
the cord K in that groove on H which gives the proper rotation
to the drum E, slowly lower the lever by means of the crank F to
a position considerably below the horizontal plane passing
through the axis of the motor. This line gives the value $W - F$
Where W is the weight of indicator lever arms, etc., tending to
rotate the rotor and F is the friction of the motor bearing. The
lever is now slowly raised to a position correspondingly above
the horizontal plane and a third line obtained on the indicator
drum, measuring the value $W + F$. The lever is now blocked
and held in a horizontal position and the crank F turned until
the spring balance reads 10 lbs. By means of a cord, the drum
is rotated and a line drawn upon it corresponding to 10 lbs. pull.
This may be repeated and the indicator card calibrated through
the range required.

After the indicator calibration record has been made the
spring balance is removed and the rope Z connected directly to
the stirrup R. Having determined the direction of rotation of the
motor when supplied with power, the line switches may be
closed, using about one-half normal voltage on the rotor. By
means of the crank F and the rope Z the lever arm is rotated
through an arc equal to that employed in obtaining the friction
curve and a record made. Make a similar record while lowering
the lever through the same arc. While the lever is ascending, the
record measures the value $W + F + T$, where T is the torque of
the motor under test; descending, the record gives $W - F + T$.
From the five curves, so obtained, the torque at any position is
readily obtained.

On these motors the cycle of torque variation usually repeats
itself regularly during a revolution. It is, therefore, only nec-
essary to continue the record throughout one of these cycles.
The indicator card has blanks for recording the machine rating,
number, and all other information necessary in connection with
this test. These cards should always be filled out clearly before
being sent to the Calculating Department.

PREPARATION OF APPARATUS FOR TEST

Inspection

Every machine during and after its assembly should receive a thorough inspection for defects, mechanical or electrical.
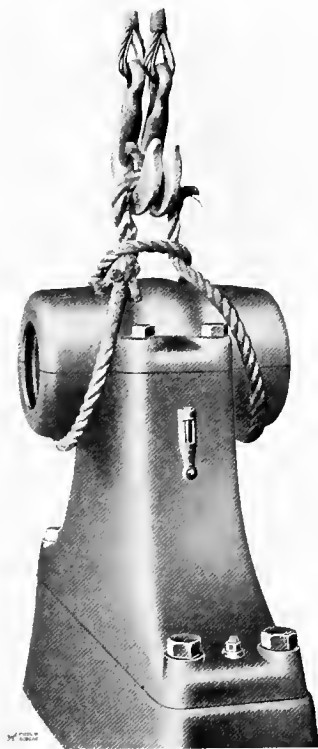

Fig. 20
METHOD OF LIFTING STANDARDS—TIGHT HITCH

The following are some that may appear: Copper bridges formed between the bars over the side mica of the commutator, due to improper turning; bent end conductor or commutator leads; damaged insulation of armature and field spools; broken insulation boards on field; insufficient clearance between bare

electrical terminals, or conductors and ground; loose terminals; brush pigtails long enough to touch either a stud of opposite polarity or the commutator, or to ground on some part of the frame; too little clearance between a brush stud or various parts of fittings, and ground.

It should be noted that laminated pole tips are not bent and that cast pole tips are of approximately a uniform thickness on all the main poles of the machine. Oil rings should
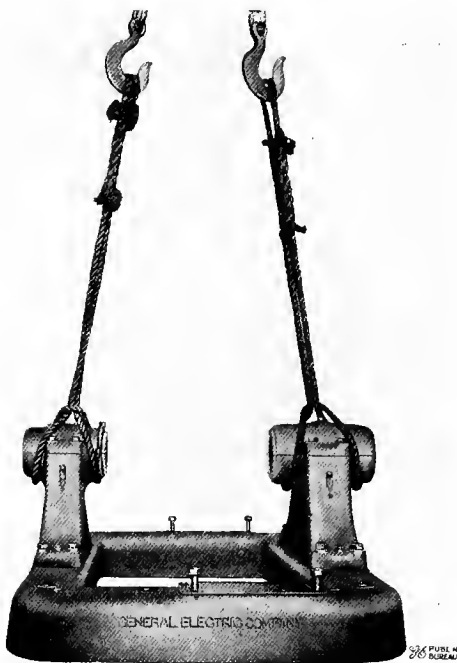
Fig. 21
PROPER USE OF SLINGS

be visible in each bearing through the bearing cap oil cover, and the bearings should be properly filled with oil.

Air gap measurements should be made from iron to iron wherever possible and never from the wooden wedges of the armature to the pole pieces. When measuring the air gap on any machine with laminated pole pieces, or laminated pole

faces, when the laminations are riveted together, the measurements must be taken between the rivets; since the gap may be slightly reduced under the rivet, and therefore a measurement at this point would not represent the true working gap of the machine. If the gap is measured where the binding bands project above the laminations, a small piece of steel, provided for the purpose, should be used over the laminations and under the air gap gauge, in order to obtain the true air gap from the armature iron to the pole piece.
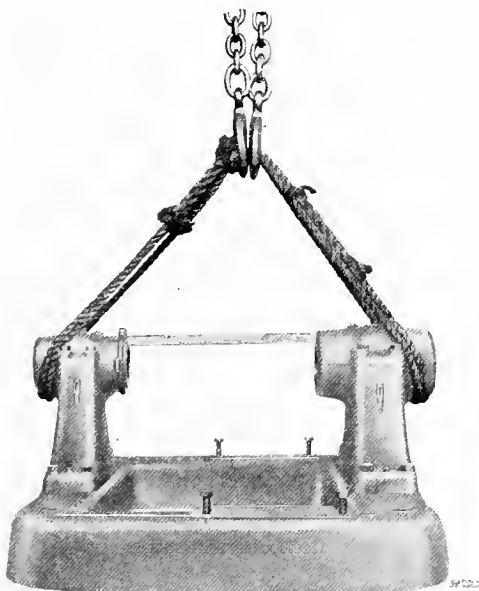
Fig. 22
METHOD OF LIFTING LONG BASE USING WOODEN STRUT

The inspection as outlined above, together with that necessary, due to the special characteristics of the apparatus, should be carefully made. Should defects be discovered as the result of this inspection, or conditions arise that may render the operation of the machine or apparatus unsafe or the results of its test inaccurate, such defects or conditions must either be satisfactorily corrected by the tester, or reported immediately to the Head of his Section for instructions before the machine is started running for its test.

Assembly

Apparatus delivered from the Manufacturing Department to the Testing Department can be divided into two general classes, *viz.:* Self-contained machines which are delivered completely assembled. Machines which may or may not be self-contained, but which are delivered to test partially or wholly disassembled. It is usually the practice to line up and center all machines carrying their own base in the machine shop before delivery to test, whether they are delivered completely assembled or not. It is, therefore, important to consider the precautions and methods which have been found necessary in assembling apparatus for test.
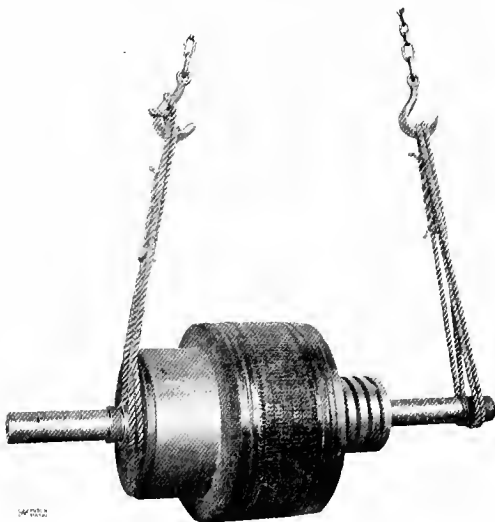
Fig. 23
METHOD OF LIFTING ARMATURE TO ASSEMBLE IN BEARINGS

Cast iron bases, especially those used in connection with medium size and large apparatus, do not possess the necessary stiffness to allow them to be erected without proper support on the iron floor or testing blocks. Care must, therefore, be taken to see that there are no chips, or lumps, under the blocking or base when setting machines in the testing stand, which may spring the base or destroy the alignment. It is well to measure the distance between pillow blocks after the base and lower half of frames are in place (in the case of split frame machines), before the rotating parts are placed in the bearings.

If the distance between the bearings is shorter than that given by the drawings, the base has been distorted, and its center is lower than the ends. To remedy this, shim up under the base until proper alignment and therefore bearing spacing is obtained.

Before placing the shaft in its bearing, the surface of bearing and journals should be well oiled. After the shaft carrying the rotating parts has been assembled, a measurement should be made of the air gap. If the air gap is not uniform, or does not agree with the drawings of the machine, the trouble must be rectified. The gap can be equalized on top and bottom by inserting shims under the frame feet. If the gap does not equalize laterally it is usually corrected by shifting the frame and redoweling the frame feet to the base.

Fig. 24
METHOD OF LIFTING LOWER HALF OF STATIONARY ARMATURE
WITH WINDINGS

All reference marks or assembly marks (usually numbers) on machines, except on those of the vertical type, will be found at the right hand side of the machine when facing the commutator or connection end. When the machine therefore is properly assembled, all marks should appear on that side.

When erecting large apparatus for test, methods of handling and transportation are of prime importance. Each piece of apparatus must of course be handled with reference to its special construction. The following observations, however, apply to the handling of apparatus in general.

Bases with pillow blocks attached, are usually lifted by hitching about the pillow blocks, as shown in Fig. 20. A long

base, or one of light section, should not be lifted by means of the pillow blocks until a strut of timber has been secured between the tops of the pillow blocks, to prevent them collapsing when lifted. See Fig. 22. As long a sling as practicable should be used to prevent undue stress in the slings themselves, since the stress increases rapidly with increase of angle between the slings. The proper application of a sling is shown in Fig 21.

Fig. 25
METHOD OF LIFTING MOTOR-GENERATOR SET

Wherever eye bolts are provided in frames or machine parts for lifting, the direction of the pull of the sling on the eye bolt must always be along its center line, otherwise a bending stress is produced which may fracture or bend the eye bolt, even under a load that it should easily carry if applied properly. Where the proper pull on the bolt cannot be obtained, a spreader must be employed between the slings. The spreader

must be secured so that it cannot slip out of position. A spreader should also be used to prevent slings, or ropes, from coming in contact with armatures or other parts of apparatus that can be damaged. Armatures are usually handled by passing the sling around the shaft. In case the armature has no
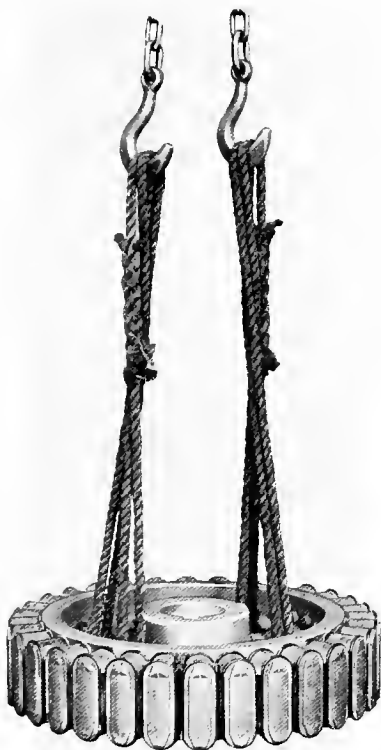
Fig. 26
METHOD OF LIFTING AND TURNING REVOLVING FIELDS
FIRST POSITION

shaft, a wooden mandrel is used in its place. Care must be taken to see that slings do not injure the end windings, or clamp ring insulation, on direct current armatures.

When lifting the top half of a direct current machine, the sling is usually passed around the top frame between two

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spools. Care is necessary to prevent slings from pressing against the spool winding or veneer flanges and damaging them. A thick, soft pad of canvas, leather, or similar material can be often used to advantage, when making such lifts. It must be understood, however, that this is not a certain preventative against damage. Unless great care is taken, spools may be
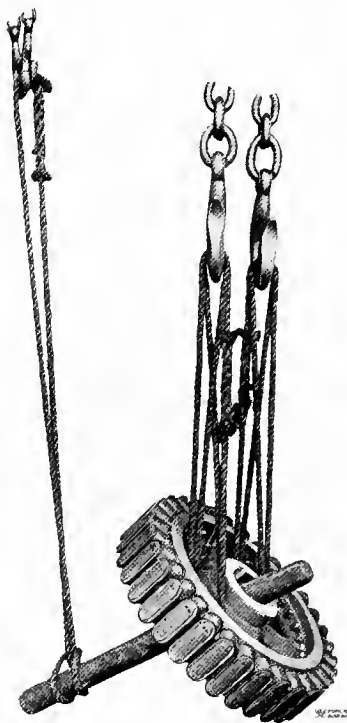
Fig. 27
METHOD OF LIFTING AND TURNING REVOLVING FIELDS
SECOND POSITION

damaged by the slings rubbing against them when turning the frame from a horizontal to a vertical position. Some stationary armatures are equipped with two eye bolts through which an iron bar can be passed. The slings should be attached to the ends of the bar in lifting.

In all cases, ropes and slings must be protected by pads to prevent chafing on casting surfaces, or edges. Figs. 23 to

27, inclusive, illustrate the more important hitches which are commonly employed.

Wiring

Though a great deal of the wiring in testing work is temporary, it must always be done as neatly as possible, due regard being paid to safety. All circuits should be protected by signs, or barriers, where there is danger of any one coming in contact with them. Conspicuously lettered danger signs are used in the Testing Department indicating the nature of the circuit. In addition to this, white tape is used around cables or apparatus carrying high voltages. After a tester has completed the wiring of a machine, he should notify the Head of Section, or Assistant Head of Section, to inspect the same. The Head of Section, or Assistant Head of Section, must then assure himself that it is satisfactory, and if so, enter his approval upon the testing record sheet and sign his name.

The following general rules should always be followed in wiring apparatus for test. First procure the print of connections, which will be furnished by the Head of the Section. The apparatus must then be connected up in accordance therewith. A copy of this print is sent to the customer with the apparatus, to help him in the installation of the apparatus.

Checking the wiring during test serves the double purpose of detecting errors in the print, or wrong connections in the apparatus. It is consequently of considerable importance.

In wiring apparatus for test, all the wiring should be completed before any of the circuits are connected to the source of power, to prevent the necessity of handling live circuits while wiring. Where possible, one hand only should be used for connecting or dis-connecting low voltage live circuits where an intervening switch cannot be used, for making final connections. It must always be remembered that any circuit may become grounded and that some circuits are permanently grounded. The 125, 250, and 500 volt direct current shop circuits are permanently grounded. Hence, in all cases, circuit breakers must be wired on the positive side of the "125 volt and 500 volt shop" circuit. As the "250 volt shop" is a part of the three wire system with grounded neutral, a circuit breaker must be used on each side, unless the permanent switchboard of the section carries two breakers, when a circuit breaker need only be connected on one side.

Opening direct current motor and synchronous motor fields is likely to break down the insulation of the apparatus, *and in the case of a D.C. motor, the motor will run away.* Wherever binding posts and connectors, as used for rheostats and small fields, are employed, a length of unbroken insulation should be stripped from the end of the temporary field wire, so that the portion stripped can be passed through the binding post and bent back over the terminal. A complete loop is thus formed which prevents the circuit being broken, even though the clamping screw in the binding post or terminal works loose.

It is not safe to insert the bare end of a wire which has previously been used in the binding post, since it may be fractured.

When a motor field is wired through the field ammeter switch, the wire leading to the switch terminal and thence to the ammeter should be continuous, the switch simply serving to short circuit the leads near the ammeter terminals. Motor field circuit breaking switches must be located so that they cannot be opened accidentally. The field switches must be provided with a holding clip, or other fastening. Single-pole switches should always be used in all field circuits in preference to double-pole switches.

In all cases, circuit breakers must be used for breaking direct currents of appreciable value. Oil switches must likewise be used on all alternating current circuits, when currents and voltages of any magnitude are in question. Never break an alternating current circuit either by water box, or by an ordinary air break switch. By so doing abnormal voltages may be produced and strain the insulation of the apparatus. All direct current generator and motor armature circuits must, therefore, contain a circuit breaker of sufficient capacity to open the maximum current delivered by the machine under test. When "feeding back" tests are made on direct current machines, two circuit breakers must be used, one in the supply circuit, and one in the motor-generator circuit through which the load energy is exchanged between the machines.

All transformers with iron cases must have their cases grounded by a substantial wire, or cable, leading to ground. This lead must be substantially connected to the transformer case and to ground, so that it cannot be accidentally disconnected.

Temporary switches, circuit breakers, etc., should never be attached to a test table or switchboard which is permanently equipped. They should be mounted on rheostat stools, or temporary stands. All temporary cables and wiring must be properly insulated from iron floors, frames, and ground. High voltage alternating current lines must be carried at a sufficient height so that they cannot come in contact with men walking under them. This also applies to disconnecting and oil switches. Cables must be kept a sufficient distance apart to take care of the potential difference between them. They must be mechanically supported so they cannot drop from their fastenings to the floor. High tension wires must be carried to the testing table from the rear. They must not be carried over the heads of men working at the test table. All high voltage wires and circuits (600 volts and over), must be regarded as dangerous. Even alternating and direct current circuits below this voltage may give rise to serious shocks or burns. No one must approach closer than 1 foot to high voltage circuits; since many circuits possess sufficient capacity or voltage to arc over before contact is made.

After finishing high voltage tests all oil and disconnecting switches must be opened before the high potential testing

cables leading to the apparatus are handled. All temporary and high potential testing cables must be disconnected from the testing transformers or high voltage source at the conclusion of the test.

Carbon Brushes

In preparing commutating machines for test, the brushes must be equally spaced around the commutator, 180 electrical degrees apart. The brushes on a stud must align properly with each other, and with the commutator bar from the front to the back end of the commutator. To space the brushes
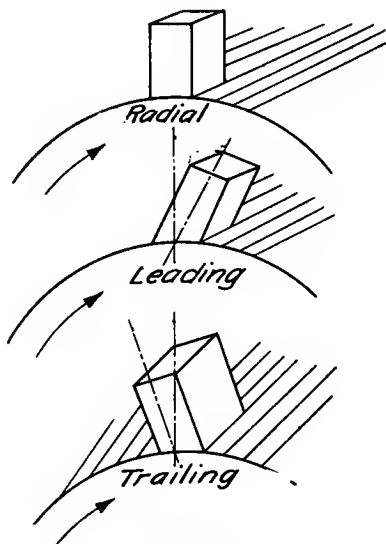

Fig. 28
RADIAL, LEADING AND TRAILING BRUSHES

place a strip of paper tape around the commutator and mark the paper where the ends overlap. Remove the paper tape and divide it with a scale, or dividers, into as many equal divisions as there are poles on the machine. Then replace the paper around the commutator and paste the overlapping ends together. Space the brushes by the marks on the paper, taking care that the holders are clamped to the stud in the proper position.

In some cases brushes are run trailing and in others leading, with reference to the direction of rotation. Radial brushes are also sometimes used.

When the brushes have been set, fit the brushes to the commutator surface. To do this, use a strip of sandpaper between the commutator and brush face. Coarse sandpaper is used first to obtain an approximate fit. Follow with very fine sandpaper. A close and accurate fit with the commutator is essential to get good commutation tests. When sandpapering, the sandpaper must be held close to the commutator, to prevent rounding the tip of the brush when drawing the sandpaper away. The sandpaper should be drawn in the direction of rotation. These instructions apply also to fitting carbon brushes on collector rings. When the sandpapering of the brushes is finished, the resulting carbon dust must be blown from the armature or rotating part. The air blast should be directed away from the rotating part, so that the carbon dust is carried completely away and cannot drift into the windings. The leading, trailing, and radial brush setting is shown in Fig. 28.

In case copper gauze brushes are used a form and file, or emery paper, must be used to fit them to the commutator or collector ring. Copper brushes are now seldom used on commutators. Copper leaf brushes, as used on Rotary Converters, are so constructed that no special fitting is required. They must, however, be properly adjusted in the holder to make good contact upon the slip ring.

Bearing Lubrication

When oil ring lubrication is used, the lubricating oil must not be allowed to get so low in the oil well that the ring does not dip into it. If this instruction is observed satisfactory lubrication will be obtained for all ordinary bearing pressures and rubbing speeds. For high bearing pressures, or high speeds, some form of forced lubrication is used. The oil is forced into the bearing either on the bottom, or the lower quarter and enters the bearing at a point such that the revolving shaft draws the oil under the shaft. Oil from forced lubricated bearings is usually returned to an external cooling tank, where its temperature is reduced before being again pumped into the bearing. Oil rings and forced lubrication are occasionally used on the same bearings, so that if the oil pressure fails the rings supply enough oil to prevent danger, until the oil pressure can be restored.

A properly designed bearing may run hot from the following causes: Oil rings sticking; scarcity or poor quality of lubricating oil; excessive local pressure in the bearing; insufficient relief on the sides of the bearings; improper alignment and excessive belt pull.

The remedy for the greater part of these troubles is obvious. In the case of excessive local pressure in the bearing, or insufficient relief on the side of the bearing, the remedy is to remove the high spots on the babbitt or bearing metal with a scraper and increase the side clearance.

The following formula can be used as a rough guide to estimate the size necessary for a given bearing. If $P =$ the

pressure per sq. in. of the projected area of the journal and $v =$ the peripheral velocity of the journal in ft. per min., then $pv =$ a constant for oil bearings. Ordinary bearings with a constant $pv = 66,000$ can be operated successfully where the peripheral speed of the shaft does not exceed 1200 ft. per min.

Before starting a machine all bearings must be filled with the proper amount of oil. Bearings should be inspected to see they have not been carelessly filled; *viz.*, that oil has not been spilled on the bearing housing, or bearing shell, or upon other parts associated with the bearing, otherwise, a false impression may be obtained as to oil leakage or throwing when under test. To give the bearing a critical test for oil leaking or throwing, the dividing line between cap and bearing

a   b   c   d
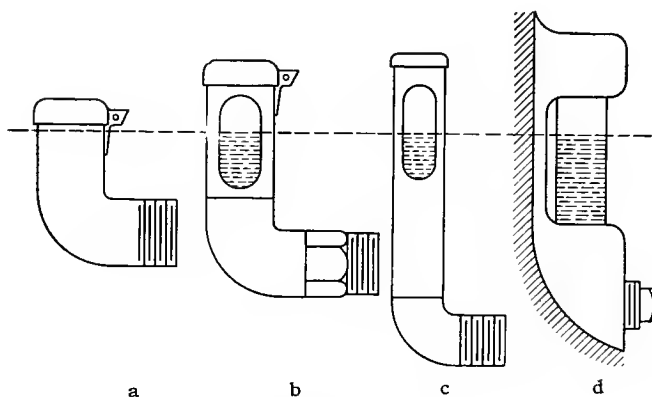
Fig. 29
TYPES OF OIL GAUGES

pedestal and between bearing brackets, should be painted with white chalk. The end of the commutator or field spider adjacent to the bearing should also be given a white coating, so that it is possible to detect, after a comparatively short run, the slightest leakage or throwing of oil.

Bearings with the end of the bearing shell visible, should be filled with oil until it touches the lower part of the shell at the end of the bearing housing. Where the end of the bearing shell cannot be seen the bearing should be filled to within $\frac{3}{4}$ in. of the top of the visible portion of the oil gauge glass; in the case of sight gauges to within $\frac{1}{8}$ in. of the top of the gauge. In the case of overflow gauges having no glass, a record of the distance of the oil level from the top of the gauge must be made, in

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every case, upon the Testing Record. Gauges with glass tubes so placed as to show the oil level (Fig. 29a) are used on bearings of large machines, and stand pipe gauges (Fig. 29b) on small and medium size machines. Overflow gauges (Fig. 29c) are those with the top of the stand pipe fitted with a hinged cap.

Oil gauges on most Induction Motors are of the overflow type, and should be filled to within $\frac{1}{16}$ of the overflow. As already stated, no oil must be spilled upon the bearing parts. In filling bearings a funnel must be used and the oil filled through the sight holes for the oil rings, or through the opening above the shaft at the end of the bearing housing.

During test no oil should be allowed to leak or be thrown from the bearings upon the rotating parts, or windings. This is especially true with reference to commutating machines, where it is important that lubricating oil be kept away from the commutator, brushes and fittings. Should oil leaking or throwing on these parts be detected during the test, the test should be immediately discontinued and the cause of leakage removed. If bearings under test rise in temperature 40 degrees, or more, above the room temperature, it should be reported to the office as a defect; since no properly designed bearing should heat above 40 degrees under normal conditions. It will usually be found that a greater temperature rise is due to a faulty bearing.

Thrust Bearings

Thrust bearings can be divided into two classes, Pressure bearings and Roller bearings.

For successful operation, the pressure type depends upon a constant and sufficient pressure of oil or other liquid to float the rotating weight and to maintain an oil film between the top and bottom bearing plates. The friction is then simply fluid friction. The pressure of oil must be kept constant, otherwise the plates will grind together and wear rapidly.

Pressures as high as 1000 lbs. per sq. in. are used in the Testing Department. The top and bottom plates are separated about .002 to .003 of an inch.

In order to insure a uniform and constant pressure, either an accumulator, a three plunger pump, or a direct acting duplex pump should be used with a baffler between the pump and the step. A difference of from 175 to 250 lbs. between the pump pressure and the pressure on the step is sufficient to give a steady pressure on the latter.

Roller Bearings

Many roller bearings are used. They generally consist, however, of several hardened rollers held in a brass retainer and arranged radially to the shaft axis. These rollers revolve between two hardened steel discs, one of which revolves with the shaft, the other remaining stationary. In this form of bearing, the oil is not under pressure but is supplied liberally

to the space between which the bearings revolve. The oil must be filled as close to the shaft as possible, so that the centrifugal force throws the oil outwards across the plates. If this is not done the oil may not flow over the plates and insufficient lubrication will result.

Stationary Apparatus

The instructions already given in reference to rotating apparatus, very largely apply to stationary apparatus. The following points must also be carefully observed in testing the latter, including transformers, regulators, compensators, switches, relays, etc.

Careful inspection must be made for mechanical or electrical defects when preparing stationary apparatus for test. The precautions already given in reference to wiring should be followed. All valves, tripping devices, contacts and insulation should be examined.

Wherever cases or receptacles are oil filled for insulation purposes, see that the proper amount of oil is put into them before test. During the test the tanks and receptacles must be carefully inspected for oil leakage, due to blow holes in castings, oil plugs, oil gauges, or due to siphoning through the leads. Adjustments of springs, weights, contacts, gauges and air gap clearances must be made before testing, so far as is practicable. No metallic particles must be allowed to drop or be thrown into transformers, regulators, etc., during test; otherwise breakdowns of insulation may result.

When testing stationary apparatus, it is rarely possible to tell from inspection whether the apparatus is alive or not. Hence there is all the more reason, on high voltage apparatus, to make use of signs and barriers, to eliminate danger and prevent shocks.

RECORD OF TESTS

For the purpose of recording the results of standard tests, various Testing Records are used to suit the different classes of apparatus. Before a standard test is made, the tester must provide himself with one of the Testing Records. He should immediately fill in all blanks and headings, with all the data concerning the machine which can be entered before the test is started. All entries must be made at once upon the Testing Record and never on "scrap paper." These Testing Records (which should contain all the results of the standard test) must be checked at the conclusion of the test, by the Head of Section in charge, to insure consistency of readings and that full and complete explanations have been made concerning the machine under test.

The completeness of these records is of the greatest importance, since they are used when passing the machine for shipment and are finally filed in the Data Department, where they are accessible for reference for the Designing Engineer and others who desire to know the characteristics of the particular machine. It is, therefore, necessary to make accurate, neat and orderly entries on the Testing Record, and supplement them with sufficient data to fully inform any one who has not personally taken part in the test. Then, if reference is made to them afterwards, no question can arise as to the meaning of any of the readings or observations made.

In general, the Testing Record is intended to be a complete and accurate history of the individual machine while in test and, therefore, every effort must be made to carry out this idea.

Special tests must be recorded on special Record Sheets. As these tests are special and often involve new or peculiar conditions, careful notes and explanations, with diagrams if necessary, should be entered to make the conditions under which the test was conducted clear.

The date of making the test, together with the name of the individual making it must always be recorded on all Testing Records and Record Sheets. In addition, whenever exhibition tests are made for our own Engineers, or for Customer's Engineers the Record Sheet must give the names of the Engineers who witness the test. Records of tests taken under the direction of a customer's Engineer must be plainly marked so that they may be distinguished from any other tests which may be taken upon the machine. It is frequently necessary to furnish the customer with "certified copies" of tests in lieu of his sending an Engineer to witness the tests and check up the guarantees. Wherever engineering instructions request "certified copies" of the test, all the necessary tests and information must be recorded on the Record Sheet so that "certified copies" can be made, demonstrating that all guarantees have been met.

When tests have been finished, all records in reference to them are sent to the Calculating Room, and such calculations made as required. Curves showing the characteristics of machines are plotted and filed with the corresponding Record Sheet. It is the function of the Calculating Room to also check up results of the Testing Records with those of duplicate machines already shipped; and, where necessary, to refer Testing Records on newly designed machines to the Engineering Department for their approval before passing the machine for shipment. As soon as the Calculating Room is assured that the test proves that a given piece of apparatus is satisfactory and has the characteristics required for our guarantees, it approves the Testing Record and the machine is listed on the "Daily Test Report."

The "Test Report" is issued daily, copies being sent to all parties interested in the shipment of the machine. It is the official notification that the apparatus is satisfactory in all respects and may be shipped.

The majority of apparatus tested is listed upon this "Test Report." Certain small mechanisms and parts which only require a slight electrical test are passed for shipment, bearing the Testing Department stamp only, to show that they have been officially tested.

Since the system of passing apparatus is largely founded on the test records, it is essential that these records be complete in every detail.

METHOD OF CONDUCTING STANDARD TESTS

In the manufacture of armatures and fields for electrical apparatus, many of the "faults and weaknesses" of material and errors of workmen can be disclosed by what may be termed "stationary testing." Faults and weaknesses may arise as follows: Through a wrong application of insulation, or through mechanical faults in it. The use of wrong material for conductors, leads, etc. Wrong assembly or connections—workmen's mistakes.

Direct current armatures are tested for grounds, short circuits, open circuits, and high resistance joints before being sent to the Testing Department. In testing for grounds a high potential is applied between winding and core; the potential depending upon the class of apparatus tested. When a ground develops in test it can usually be located by smoking the insulation at the breakdown point.
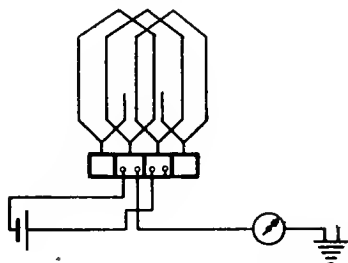
Fig. 30
TESTING FOR GROUNDS

If a low resistance ground has developed it may be quickly and accurately located by the following method: A low voltage current is passed through the armature winding from a commutator bar to the one adjacent to it, which is sufficient to give a readable deflection on a galvanometer or millivoltmeter (as shown in Fig. 30). A line is connected to a galvanometer to ground, the other galvanometer connection being placed on one of the commutator bars. Then pass the supply and galvanometer leads from segment to segment, until a full deflection is obtained and zero reading when the leads are moved one segment further. The grounded coil then lies between the bars, for which full deflection was obtained.

A bar to bar test is usually made to disclose short circuits, open circuits, and other similar faults. For this test the windings connected to two adjacent commutator segments have their resistance measured by the "drop of potential method," as indicated in Fig. 31. Storage batteries should be used and

a special electro-magnetic d'Arsonval galvanometer. With this arrangement readings can be obtained rapidly, as the instrument is "dead beat."

Measuring the ohmic resistance of the winding will sometimes reveal a wrong connection, which, on a bar to bar measurement, would give a uniform deflection all around the commutator. Series or wave windings may sometimes have all the conductors joined in series, but in the wrong order, so that the armature is inoperative. In the case of multiple or lap windings, double, triple or even quadruple spiral re-entrant windings are possible, whereas a single spiral is required. In taking a resistance measurement for brush to brush or a running resistance of the armature, see that the measurement is made from the proper commutator segments. For multiple or lap windings, the resistance measured from diametrically opposite points divided by half the number of poles squared will give the true running resistance, while with a series or wave winding the resistance should always be taken at points 180 electrical degrees apart. For example, take a four-pole armature with a lap
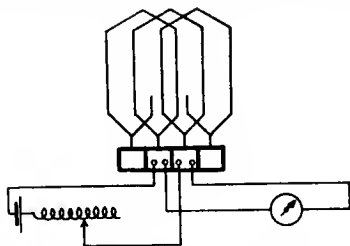
Fig. 31
TESTING FOR OPEN CIRCUIT

winding and 360 commutator segments. This should have its resistance measured between bars No. 1 and No. 181. The resistance divided by four will give the running resistance. With a wave winding on the same armature, the resistance measurement should be taken between bars No. 1 and No. 91, this resistance being the true running resistance.

Alternating current armatures and fields are similarly tested for grounds, short circuits, open circuits, wrong connections, polarity, etc. In testing for grounds the same methods and similar apparatus are used as for direct current machines, except that with alternating current, the voltages generated and used are usually higher and, consequently, the testing voltages are correspondingly higher and greater care must be taken in testing. All high potential tests must be made with carefully calibrated electrostatic voltmeters that have been checked with a spark gap. The testing equipment should be as near the apparatus as possible, since the additional capacity of testing lines may raise the voltage at the receiving end much

above that at the generating end. Unless this precaution is taken, excessive voltages may be applied which may damage the insulation. In case a ground develops a resistance measurement will generally locate the point at which it occurs, unless each phase has two or more multiple circuits. In the latter case it may be more readily located by opening one or more cable joints and separating the circuits.

A measurement may then be taken in the following manner: First, measure the resistance of the grounded circuit or phase. Second, measure the resistance to ground by connecting one line to ground. Third, measure the other end of the resistance to ground, by connecting one measuring line at the other terminal of the phase and one to ground. If all measurements have been accurately made the sum of the second and third will be equal to the first, and the location of the ground will be as far from one terminal, as the measured resistance from that terminal to ground is of the total resistance of the circuit.

This test is shown in Fig. 32, which represents a single circuit, or phase, of an alternating current machine, with a ground as shown. If the resistance between A and B is one ohm, between A and G .35 ohms and between B and G .65
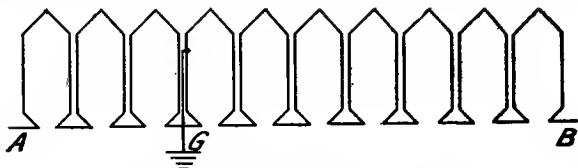
Fig. 32
TEST FOR GROUNDS ON AN A.C. ARMATURE

ohms, the location of the ground is 35/100 of the distance between A and B, from A. As 10 coils are in the circuit the measurements show that the fourth coil is grounded, counting from A.

In the case of an alternating current winding the ohmic resistance measurement will not always detect a wrong connection, such as a reversed coil, pole section, or phase; since, although the copper resistance would be measured correctly the total winding might be partly reversed and, therefore, inoperative. Such faults may be discovered by a polarity or impedance test, with alternating current. For this purpose a single-phase current can be used, since a reading may be taken on the different circuits, or between pairs of terminals successively by shifting the testing lines until the whole windings have been tested.

Short circuited coils on moderate size machines can be readily tested by using a wound electro-magnetic yoke excited with alternating current. This yoke is dropped over a portion of the armature coil after the coils have been placed in their slots. The yoke and armature form an alternating current

transformer, with the yoke winding as primary, and the armature coil as secondary. If there is a short circuited turn, layer or coil in the armature, the magnetizing current in the yoke winding rises. If the current is maintained a short time, the insulation on the short circuited section will warm up appreciably, or burn sufficiently to indicate the defective coil.

On larger size alternator armatures, tests may be made for short circuits by passing alternating current through the armature coil itself. In this case it is usually necessary to increase the reactance of the coil by placing a magnetic bridge over its armature slots after it has been assembled in the core.

The above tests may be made with the apparatus at rest. The Armature Department, therefore, uses them for detecting faults and correcting them before delivering the parts to the Testing Department. These faults can be more readily corrected when apparatus is being wound, with a saving resulting in time and cost. It is, however, sometimes necessary to test by these methods, after apparatus has been received in the Testing Department, in order to locate faults which have developed later.

Practically all direct current machines are delivered to the Testing Department unassembled, with the exception of railway motors and some government motors. As the armature field frame, field spools and fittings for the machine are delivered separately direct from the shops in which they are built, the complete assembly is done in the Testing Department to prepare for testing and subsequent shipment.

To assemble a machine, first mount the field spools upon the frame, and connect them, in accordance with the connection print, which is furnished for each machine. As soon as this is done, and before the frame is taken from the spool assembly stand, test the windings electrically for resistance and high potential. Also test for polarity of the poles by exciting the field coils. These tests check the assembly of spools and test their position upon the frame. In testing field coils for polarity, all field windings must be tested separately to ascertain if the series, shunt, and commutating pole windings are wound and assembled so as to give the required polarity. Polarity may be tested by the use of a compass; in this case the compass must not be carried too near to the pole, otherwise it may be demagnetized, or even reversed. To test for opposite polarity of alternate poles, bridge two pole tips with a piece of soft iron. If the polarity of the poles differ the piece will be strongly attracted, whereas if the poles are of the same polarity much less attraction will be exerted.

Drop on Spools

With a given current flowing through the field, the difference between the voltage drop on the spool having the highest and the one having the lowest resistance must not be more than 9 per cent. on direct current and 14 per cent. on alternating current machines, using the average drop as the base. If the drop

is greater the matter should be referred to the office for instructions. The field spools for alternating current apparatus are assembled on the field spider in the Armature Department; hence, it is only necessary to take a resistance measurement per spool before using them for a test. In recording the drop on spools, they must be numbered in a clockwise direction beginning at the spool next to the opening in the shunt field when facing the commutator. Whilst testing a machine a very careful record must be kept of all winding resistances. Many armatures when delivered to test are fitted with equalizing rings, which make it impossible to obtain the true armature resistance. The Armature Department's tag, attached to the armatures when received in the Testing Department, gives armature resistance, which was obtained before the connection of the equalizing rings. The tester must, therefore, record the Armature Department's measurement of resistance on the Testing Record.

Resistance

The armature resistance is rarely measured in the Testing Department. Such cases are specified when required. The shunt field resistance is obtained by the "drop method," using an ammeter and voltmeter. This measurement is required on each machine before a test is started. For measuring the series field resistance a special galvanometer measuring set must be used, with which the various testing sections are provided. As a considerable amount of the resistance of a series field may consist of the contact resistances between the spools, all connections must be carefully cleaned and clamped tightly together, before taking the resistance.

Insulation Resistance

A measurement of the insulation resistance is occasionally taken upon direct current machines and alternators. The Government requires this measurement in most cases. An insulation resistance measurement is frequently taken on alternators of 2300 volts and above. On commercial apparatus generally, the measurement of insulation resistance, however, is unnecessary, since the materials used have ample dielectric strength and the slight leakage which a low insulation resistance would indicate is unimportant.

Air Gap

The measurement of air gaps is important on all apparatus. Air gaps on direct current machines are measured in the following manner: With the armature stationary, the gap should be measured at both the commutator and pulley ends, the measuring scale being inserted under each pole tip, without including the chamfer of the tip. A mark should then be placed on the armature circumference under a given pole and the armature revolved through one pole span. The air gap measurement should be taken under every pole tip at the commutator end.

The first set of measurements are known as the "stationary gap"; the second set as the "revolving gap."

An eccentricity test of the armature is made by marking a point on one pole piece and measuring the air gap between this point and several equally space points around the surface of the armature punchings. These readings at once show if the armature is eccentric. If the eccentricity is large the matter should immediately be reported to the office.

The maximum air gap on direct current machines, when measured from iron to iron, should not differ from the minimum air gap by more than 15 per cent. of the average measurement, and not more than 20 per cent. when measured from the armature binding wire to the iron of pole piece.

On commutating pole machines the air gap measurement is taken under the center of the commutating pole. It is also necessary to measure the distance between the tip of each commutating pole and the adjacent tip of the main pole. The maximum allowable variation in this measurement is 3/32 in. Should this amount be exceeded the matter should be referred to the office for instructions before proceeding with the test.

Air gap measurements are taken on alternating current machines with the revolving field stationary, and also by revolving it in a similar manner to that given above for "stationary" and "revolving gap" on direct current machines, except that the air gap measurement on A.C. machines is taken at the center of the pole piece both on the front and back ends. In measuring the "revolving gap" it is not necessary to take the air gap measurement under each pole. The measurement need only be taken at points spaced 45 mechanical degrees apart. That is, eight (8) sets of measurements are required for the "revolving gap."

Since the air gaps of induction motors are small, and since a uniform gap is important, they are measured by special gauges provided for that purpose. In using these gauges they are passed completely through the motor air gap from end to end of the punchings. This gap measurement is taken at several points about the circumference of the rotor with it stationary and revolving in a similar manner to that indicated above.

Testing instructions which are issued from the office, in the case of special machines, give the length of air gap required for a particular machine, hence the length of air gap measured should be checked against this information. If discrepancies exist, the matter should be immediately referred for instructions, before starting the machine for test. When air gap measurements are made, a critical inspection should be made of the clearance between the rotor and windings or other parts, to insure that it is sufficient to allow the machine to operate without any surfaces striking or rubbing together. This may occur if the windings project unnecessarily and in no case must clearances be so small as to be unsafe. Should such cases occur, the trouble must be corrected and the proper clearances obtained before the machine is started for test.

Before starting a machine for the first time, the tester must follow the instructions given in pages 65 to 78, in reference to the mechanical and electrical conditions, the wiring of the various circuits, lubrication, installation, etc. The belt lacings must be watched to prevent them opening during test. Pulleys must be inspected by the regularly appointed Pulley Inspector to make sure they are securely fastened on the shaft and that they are mechanically strong. All keys, set screws, or other rotating parts which may catch in the clothing, or injure others must be properly protected. All keyways must be provided with covers or guards. All shafts carrying one-half of a solid coupling must have that part boxed in, so that workmen may not come in contact with the sharp edges which usually exist. No loose particles must be allowed inside any rotating or stationary parts.

If a machine has been standing for any length of time, before it is started again the same precautions must be observed. These points are strongly emphasized in reference to all vertical apparatus, where the danger of dropping things into a machine, while running, or of workmen leaving tools in dangerous places on or about the machine is very much greater than with horizontal apparatus.

When apparatus is first started it should be brought to speed very slowly and carefully watched to see that everything is correct as the speed increases to normal value. Reliable tachometers, or speed indicating devices must be used in starting to prevent a dangerous increase of speed. Oil rings must be examined at slow speed to see if they are carrying sufficient oil to the bearings. In the majority of cases, oil rings should turn when machine is running at $\frac{1}{4}$ speed, and properly lubricate the bearings.

The balance of the rotating parts should be carefully noted until the machine has reached its normal rated speed. If the apparatus does not run without vibration the matter should be reported as a defect. The vibration must be remedied before the test proceeds. Vibration due to the running of the machine may indicate lack of balance, whereas it may be really due to improper alignment, or to springing of the shaft. When unbalancing occurs in operating machines running above 1200 r.p.m. correction must be made by dynamic balancing. This method will be described later.

Saturation

In order to ascertain the characteristics of the magnetic circuit, a test known as "saturation" is made. The characteristic curve may be obtained by any of the following methods; "generator saturation", "motor saturation," and "ballistic saturation."

The test usually made is "generator saturation." To obtain a saturation curve by this method, the machine is driven as a generator, preferably at constant speed. If, however, a set of readings is known for one speed, they can be obtained

for any other by direct proportion. Hence a saturation curve taken at any constant speed at once gives the saturation curve at any other speed. The brushes of direct current machines should always be set on the neutral point when taking a no-load saturation.

In taking a saturation curve on polyphase alternating current generators, a reading of the voltage across each phase must be taken at normal field current, to see if the phases are properly balanced. If they do not balance, they must be made to do so. On Rotary Converters careful readings should be taken of the direct current voltage, as well as the alternating current voltage between all phases with the field excitation giving normal voltage. The phase voltages must be also closely balanced.

The usual method of taking a generator saturation curve is to hold the speed constant, and then increase the field current step by step until at least 125 per cent. of the normal voltage of the machine is reached, taking readings at each step simultaneously, of volts armature, volts field, and amperes field. After reaching the maximum value of the field current, without opening the field, reduce the current gradually in four or five steps, and again take readings to determine the value of the residual magnetism at various points along the curve. Special care should be taken to insure accurate readings at and above normal voltage, since with alternating current generators, this is the portion of the curve used for calculating the regulation under load. Whenever saturation curves are taken, a record of the air gap from iron to iron should be made upon the record sheet, together with the armature and field specifications.

Motor Saturation

When it is inconvenient or impossible to drive the machine as a generator, a "motor saturation" may be made. In this case the machine is operated as a free running motor. The driving power must be furnished from a variable voltage circuit. A certain voltage is impressed upon the armature and the motor field weakened or increased in the case of direct current machines to give normal speed, and a record made of the volts armature, amperes armature, amperes field, volts field, and speed. The starting voltage should be at least 50 per cent. lower than the normal voltage of the apparatus. The applied voltage at the armature should be increased by steps to 25 per cent. above normal value, and the field increased correspondingly to keep the speed constant, the same readings being recorded at the various steps as before. Readings should also be taken at three or four points, as the impressed voltage and field current is lowered to approximately the value at the beginning of the test.

Care should be taken when testing direct current apparatus, as unstable electrical conditions may develop, and excessive speeds result. The circuit breaker in the armature circuit of the motor driving the machine must, therefore, be accessible to the tester reading the speed.

On alternating current apparatus, the machine is run as a motor and the impressed voltage varied as already described. The speed is independent of the motor field in this case, and instead of regulating the motor field for speed it should be regulated to give minimum input current at each voltage. Readings should be taken of voltage impressed, amperes armature, amperes field, and volts field. With Induction Motors it is only necessary to impress variable voltages at constant frequency and record readings of volts armature, impressed amperes armature, and speed.
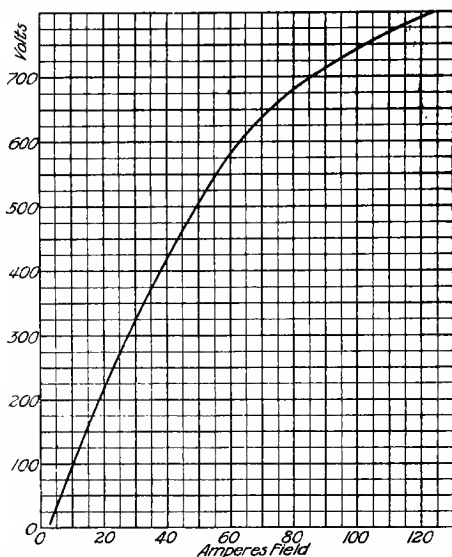
Fig. 33
SATURATION CURVE ON A 500 KW., 600 VOLT, 20 POLE, 360 R.P.M. 3-PHASE 60 CYCLE A.C. GENERATOR

The calculation of saturation tests is very simple, as it only consists in applying instrument correction factors and ratios, and plotting upon coördinate paper, volts armature as ordinates and amperes field as abscissæ. Fig. 33, Calculation Sheet No. 1, shows the results of a saturation test made by either of the above methods.

Ballistic Saturation

In order to make a generator or motor saturation test, the machine must run at, or near, its normal speed. Sometimes

it is desirable to test for saturation without the delay and expense of setting up and operating the machine. In this case a test known as "ballistic saturation" can be used, obtained as follows:

First, a machine of given armature winding, armature core, and field structure is operated for a running saturation test as already described. The machine is then shut down and its brushes shifted 90 electrical degrees from their no-load neutral position when the machine is running. The shunt field of the machine is wired to a source of excitation and provided with a field reversing switch so that the field circuit may be quickly opened and reversed. This permits of the field current being interrupted at any value, quickly reversed, and allowed to rise to the same value again. Leads from a ballistic galvanometer are then connected to the armature directly under the center of the brushes of two adjacent studs, all other brushes being removed. The galvanometer circuit should have a resistance such that the voltage induced in the armature, when the field is broken at a maximum current value and reversed, is just sufficient to give the maximum scale deflection on the ballistic galvanometer.

A ballistic curve may be then obtained, from which the running saturation curve can be readily obtained. Galvanometer readings are taken at a number of field current values as in the running saturation tests. The magnetic flux due to each current value is proportional to the induced voltage in the armature when the field is broken and reversed by means of the reversing switch. Hence, if the galvanometer deflection is plotted as ordinate with the field current values, a curve similar to the running saturation curve will be obtained, which bears a definite relation to it, depending upon the armature windings, leakage coefficient, galvanometer constant and resistance of the galvanometer circuit. Before taking galvanometer readings at a given field current value, the field current should be reversed one or more times in order to obtain the same magnetic conditions as were obtained in the running saturation curve. Unless this precaution is observed, the saturation curve deduced will not agree closely with the running saturation test of the same machine.

The running saturation for any machine may be calculated from the machine constants, and this test without further information. Such a calculation is somewhat involved, however, and uncertain. It is best to take the ratio of the galvanometer deflection for a given field current to the armature voltage generated when the machine is running at normal speed with the same field current for excitation. This ratio will hold with sufficient accuracy for all practical purposes throughout the ballistic test and hence allow of a ready determination of a running saturation curve being obtained on any duplicate machine as regards armature winding and core, and field structure. This method may be used to great advantage to check up individual standard machines, and insure that the magnetic

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circuit and windings are correct. Similar machines should be tested using the same galvanometer and resistance values.

Much time and expense can be saved by using this method, when the erection of the machine in the testing stand requires considerable labor. To obtain the ballistic curve, the armature need only be wedged central with the field bore by wooden or composition wedges to obtain a uniform air gap. Fig. 34 shows the results of a ballistic test and running saturation test, plotted on the same sheet.
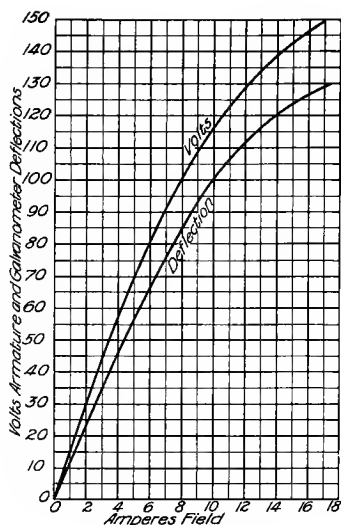
Fig. 34
BALLISTIC AND RUNNING SATURATION ON A 75 KW., 125 VOLT
6 POLE, 375 R.P.M. COMPOUND WOUND D.C. GENERATOR

Core Loss

Three methods are used by the Testing Department to measure the core losses on rotating direct current apparatus and alternating synchronous apparatus. They are known as follows: "Running light core loss," "Belted core loss," and "Deceleration core loss." The "running light" test is made for all direct current generators and motors which are given a running test. It is occasionally, though not frequently, employed with alternating current synchronous apparatus.

The following conditions must be obtained with direct current apparatus in order to give satisfactory results: Brushes must be shifted on the commutator to the no-load neutral point

They must have their normal tension and the commutator must be clean, so that the normal operating commutator and brush friction values are obtained. This test, wherever possible, should be made after all the others have been finished, in order to have a glossy commutator with its surface in good operating condition. The driving power should be supplied from a variable voltage circuit that is not subject to sudden fluctuation. Since the power input required to drive the machine running free as a motor must be obtained, its value must not be read when the rotating parts are either accelerating or decelerating. A steady voltage must be kept on the armature and the field current must have a constant value.

When "running light" tests are made on direct current generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator increased by the IR drop in the armature at full load. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage and speed.

If the machine in test is a direct current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, less the IR drop in the armature under full load. The field current is then adjusted to give normal speed and electrical and speed readings taken, as outlined above for direct current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature I^2R losses have been subtracted.

In making records of these tests, the Testing Record must clearly show whether the running light current consists of the armature current plus the shunt field current, or whether it is the armature current alone. To check this point, open the armature circuit with the shunt field circuit closed, and note whether any current is indicated on the ammeter, reading the power supplied. If no current is indicated, the reading indicates the armature current alone, otherwise, the running light current is equal to the sum of the armature and field currents. To obtain "Running light" core loss tests, only a single field winding must be used for excitation; this must be a shunt field winding.

In order to obtain running light core loss upon alternating synchronous machines (in which class Rotary Converters are not included as the core loss test on these machines is similar to that on direct current machines), they should be operated as synchronous motors at the proper frequency and rated voltage. For the best results, both frequency and voltage must have a steady value.

With normal voltage on the armature, the direct current field should then be varied until minimum armature current is obtained. Readings should then be taken of amperes and

volts of all the phases. At minimum input current unity power factor is obtained and, therefore, the power to drive such machines will be the volt ampere input. Wattmeters may be used in addition to check the volt ampere readings. This measurement includes friction and windage losses, together with open circuit core loss, plus the I^2R loss in the armature. If the value of the core loss need not be separated from the other losses, the test is useful for checking up full load efficiencies. For direct current apparatus this test is obtained quickly and at less expense than by other more elaborate methods, and the results are just as accurate and satisfactory.

Belted Core Loss

The "belted core loss" method separates the core loss from the bearing friction, brush friction, and windage. A small direct current motor is used to drive the machine under test as a generator at its rated speed. A belt drive between these machines is most commonly used. However, wherever great accuracy or a high speed is necessary, direct driving by a coupling is often used.

The driving motor for this test must be carefully chosen. It must be operated through the range of load required for the core loss test with good commutation and with a fixed setting of the brushes. Ordinarily a safe rule to follow is that the motor should be approximately 10 per cent. of the capacity of the machine under test. The maximum load which this motor should carry with the heaviest field on the machine under test should not exceed 50 per cent. of its normal rated capacity. The driving motor should be operated as nearly as possible at its rated speed and field strength. The brushes should be carefully set at the best position for good commutation at all the loads required by the test. The commutator surface should be in first class condition.

The weight and width of the belt must be selected to give minimum loss. When testing motor-generator sets, rotary converters, and apparatus that do not use belts, the tension of the belt must be kept as low as practicable, so that the bearing friction is not increased due to the belt pull. Endless belts should be used in preference to laced belts.

The driving motor must be wired so that readings may be taken of amperes armature, volts armature, amperes field, and speed. A reading should be taken on the motor corresponding to normal speed of the machine under test. The machine under test should be wired with its field separately excited and provision made for reading amperes field, volts field, and volts armature. Careful resistance measurements must be made, previous to starting the test, of the armature of the driving motor.

The test is then carried out, as follows: The field of the driving motor is adjusted to about normal value and excited from a source of constant voltage so that its value may be held constant throughout the test. The speed of the driving

motor is regulated by varying the voltage applied to its armature terminals. First, run the driving motor and the machine under test a sufficient length of time to allow the friction to reach a constant value. This will be obtained when the input on the driving motor becomes constant when driving the machine under test without any field excitation. Careful readings should then be taken first of the input to the driving motor with the machine under test unexcited and all brushes down on the commutator. Following this reading, a second should be taken with all brushes raised from the commutator of the machine under test. The difference between these two sets of readings will give the brush friction on the machine receiving test. Starting with the zero field on the machine under test, observations of the input to the driving motor should be made at various values
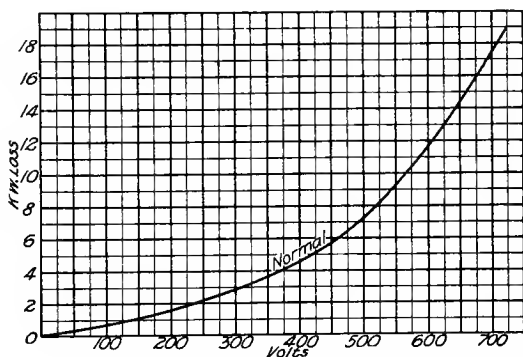
Fig. 35
OPEN CIRCUIT CORE LOSS ON A 500 KW., 600 VOLT, 20 POLE, 360 R.P.M.
3-PHASE 60 CYCLE A.C. GENERATOR

of the field up to that which will give 125 per cent. normal load voltage. Correcting the motor input at these various field strengths by taking out the I^2R loss in the armature of the driving motor, and subtracting the power input to the driving motor with zero field, the core loss is left corresponding to the various field strengths.

In order to insure constancy of friction losses during the entire test, the readings of the motor input with zero field should be repeated at least three times during the progress of the test; namely, at the beginning, again near the middle point of the curve, and lastly at the end of the test. Readings should also be taken at the end of the test with normal voltage field current and with brushes raised from the commutator, to compare with the reading in which the same field was used

with the brushes resting on the commutator, and with the set of readings giving the brush friction.

The tester should check these values, one against the other, to see that they are consistent before turning in the results of the test. To check the results of the core loss as the test proceeds, the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. This should give a curve similar to Fig. 35. If a satisfactory curve is obtained, the driving motor can be unbelted and a running free reading taken upon it, holding the same amperes field as were used during the test.
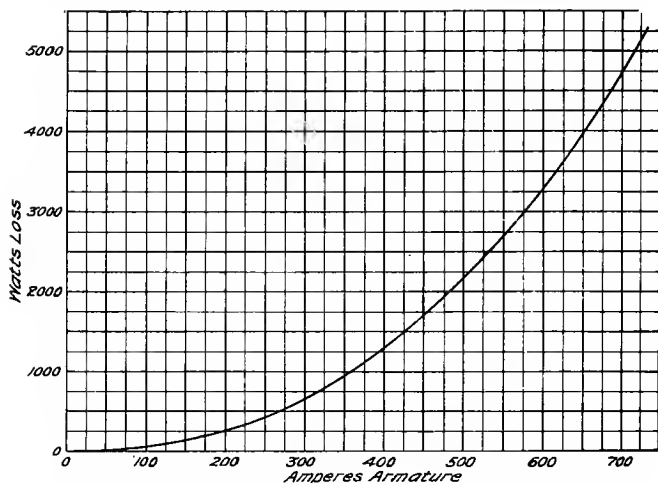
Fig. 36

SHORT CIRCUIT CORE LOSS ON A 500 KW., 600 VOLT, 20 POLE 360 R.P.M., 3-PHASE 60 CYCLE, A.C. GENERATOR

The bearing friction and windage losses of the machine under test can be separated.

For a successful core loss test, all readings must be made at absolutely constant speed, when the rotating parts are neither accelerating nor decelerating. All field currents must be held constant. No pulsation or sudden variations must occur in the armature current of the driving motor which might vitiate the power readings.

In making out reports of core loss on the Testing Records, the following data should be recorded in addition to the electrical readings already mentioned: *viz.*, circumference of commutator; circumference of shunt and series field spools; height

of shunt and series field spools; number and width of commutator bars; size and material of brushes; number of studs and brushes per stud; brush pressure per brush; rating of driving motor together with its armature and frame number; and the type and rating and number of the machine under test. On series motors core loss tests should be taken at several different speeds covering the range of the speed curve. The method used is identical with that described above, and will be considered in connection with railway and series motor tests.

Synchronous alternating machines generally have loss measurements taken as outlined above on open circuit and also with the armature of the machine under test short circuited. In the latter case, the increase in power supplied by the driving motor over that required by the friction loss is plotted as ordinate against the amperes armature as abscissæ, or the open circuited armature voltage due to a given excitation. A curve is obtained similar in character to the open circuited core loss curve. Such test is commonly known as "short circuited core loss." Fig. 36 shows the results of such test after all correction factors have been applied. In making this test careful measurements must be made of the resistance of the short circuited armature circuit including all leads, before and after the test, since to obtain the true short circuited core loss, the I^2R loss must be subtracted. Observations should be made with the short circuited armature current at least 200 per cent. of its normal full load current.

Deceleration Core Loss

It is often necessary to determine the core loss friction and windage losses of large machines when it is impracticable to employ the "belted core loss" method. The "running light" reading alone does not allow the separation of the core loss from friction and windage. A method known as the "deceleration core loss" is used for this purpose. Such tests are employed regularly on turbine-driven units, and it is very convenient to use them in connection with certain vertical waterwheel-driven generators, and other exceptionally large horizontal alternators and direct current machines with a considerable flywheel capacity.

A running light reading at normal speed and normal voltage should be taken to give the driving power necessary under that condition. Where this is not practicable, the moment of inertia of the rotating part must be known. This can be very accurately calculated for the majority of machines from their mechanical dimensions, as given by the working drawings. The test is as follows: First drive the machine with no field at a little above normal speed, and then suddenly cut off the driving power and observe the deceleration, then do the same thing with full field on the machine. In the first case the deceleration is due to the retarding force—is due to friction and windage, in the second case due to these factors plus core loss. Readings of the speed of the rotating parts should be taken at sufficiently

frequent intervals to obtain a uniform and reliable curve. A set of these curves is shown in Figs. 37 and 38. With the aid of these curves together with a "running light" test, or a calculation of the kinetic energy of the rotating parts, a determination of the value of the core loss, and also of the friction and windage, is readily made. The following is a brief derivation of the formulæ used in calculating such results by either method.
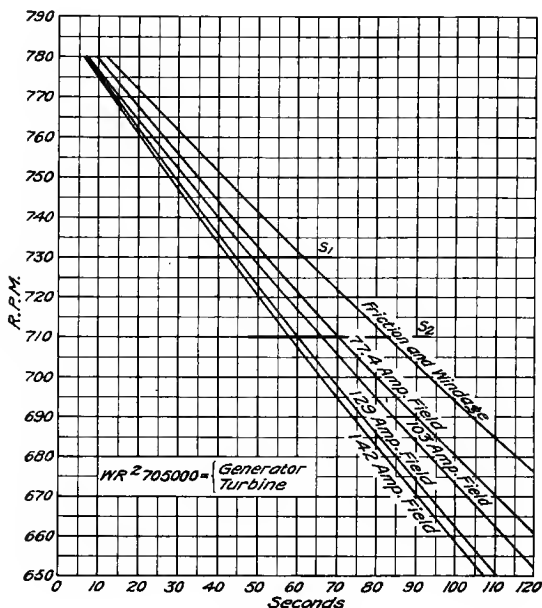

Fig. 37
DECELERATION CURVES ON A 3000 KW., 2300 VOLT, 720 R.P.M.
60 CYCLE, 3-PHASE, A.C. GENERATOR

If M = mass.
   W = weight.
   v = linear velocity at radius of gyration.
   ω = angular velocity.
   S = speed r.p.m. corresponding to angular velocity.
   g = 32.2 ft. per sec. per sec.
   r = radius of gyration.
   Wr^2 = flywheel effect.

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E = kinetic energy at speed s and time T
E_1 = " " " " " S_1 " " T_1
E_2 = " " " " " S_2 " " T_2

Then $\dfrac{E_1 + E_2}{2}$ = average kinetic energy from T_1 to T_2

The kinetic energy of a rotating body at any instant is equal to $\frac{1}{2} M v^2$

$$\frac{1}{2} M v^2 = \frac{W}{2g} v^2 = \frac{W}{2g}(r\omega)^2 \text{ where } \omega = \frac{2\pi s}{60}$$
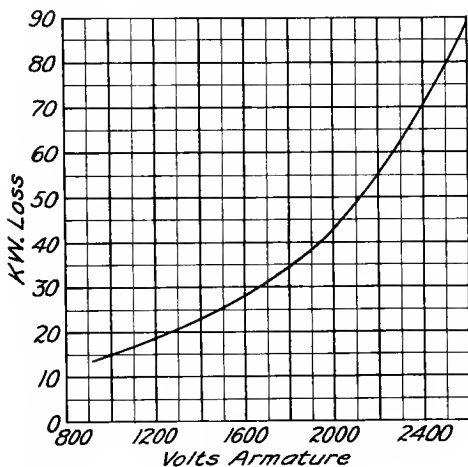
Fig. 38

OPEN CIRCUIT CORE LOSS CURVE TAKEN FROM DECELERATION
CURVES IN FIG. 37

The energy consumed in decelerating from ω_1 to ω_2

$$= \frac{Wr^2}{2g}(\omega_1^2 - \omega_2^2) = .00017 \ Wr^2 (S_1^2 - S_2^2) \text{ foot pounds.}$$

$$\frac{E_1 + E_2}{2}(T_2 - T_1) = .00017 \ Wr^2 (S_1^2 - S_2^2) \text{ or } E = .00017 \frac{Wr^2 (S_1^2 - S_2^2)}{T_2 - T_1} \text{ ft. lbs. per sec.}$$

Therefore, $\text{kw.} = \dfrac{.00017}{} \dfrac{Wr^2 (S_1^2 - S_2^2)}{T_2 - T_1} \times \dfrac{746}{550} \times \dfrac{1}{1000} = \dfrac{2308}{10^{10}} \times \dfrac{Wr^2 (S_1^2 - S_2^2)}{T_2 - T_1}$

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If T_3 and T_4 are respectively the times at which the speeds S_1 and S_2 occur with no field on the machine, then kw.

in this case $= \dfrac{2308}{10^{10}} \dfrac{Wr^2 \; (S_1^2 - S_2^2)}{T_4 - T_3}$

The kw. core loss is then the difference between the kws. obtained by the formulæ given above.

If the kw. running light has been obtained, kw. running

light $= \dfrac{2308}{10^{10}} \dfrac{Wr^2 \; (S_1^2 - S_2^2)}{T_2 - T_1} = K \dfrac{Wr^2 \; (S_1^2 - S_2^2)}{T_2 - T_1}$

Therefore $Wr^2 = \dfrac{\text{kw. running light } (T_2 - T_1)}{K \; (S_1^2 - S_2^2)}$

Also kw. friction $= \dfrac{K \; Wr^2 \; (S_1^2 - S_2^2)}{T_4 - T_3}$

Or substituting for Wr^2

Kw. friction $= \dfrac{T_2 - T_1}{T_4 - T_3} \times$ kw. running light.

Hence knowing "running light," the friction can be calculated and the core loss separated from the "running light."

With "deceleration core loss" records, the same data must be entered upon the record sheets that are required in connection with the "belted core loss" method. Calculation Sheets 2 and 3 show the standard method of calculating test results, open circuited and short circuited, taken by the "belted core loss" method. Calculation Sheet 4 shows the method employed in calculating results of "deceleration core loss" either by using the value of the moment of inertia of rotating parts, or "running light" test. For Calculation Sheets see pages 395 to 411.

Field Compounding

Field compounding tests give the additional ampere turns field necessary to overcome armature reaction and IR drop in a machine from no load to full load. The test is made by separately exciting the field of the machine under test, in order to hold the voltage at its terminals constant as the load is increased from no load to full load. Readings of amperes field, volts field, amperes armature, volts armature and speed are taken at no load and at least three intermediate points between no load and rated load. It is generally required, and usually advisable, to take an observation at 25 per cent. overload, if the power is available. All readings should be made with a rising field current. On polyphase apparatus the phases should be loaded equally so that their currents will be properly balanced. Fig. 39 shows a curve of field compounding in which is plotted amperes field or ampere turns as ordinates and amperes armature as abscissæ. See Calculation Sheet No. 5.

Maximum Output

The maximum output of direct current compound wound generators is dependent upon their commutation, or heating limitations, hence, the maximum output test on these machines is usually a commutation test, which will be described later.

As in shunt wound generators the voltage falls with the load at constant field excitation, the maximum ouput is not always limited by commutation. It is not usual to make maximum output tests, however, on the above machines, since they possess little practical interest.

In the case of Induction Motors, the maximum output, or breakdown point, is a matter of considerable importance. If sufficient power is available, the motor is loaded in successive steps, beginning at zero load up to the breakdown point. During this test readings of volts armature, amperes armature, speed, and motor output are taken and plotted. It is essential that the voltage and frequency of the power circuit from which the motor is operating be held constant. It is also important that readings be taken quickly at overload currents, and that the motor be allowed to cool between such readings, or it will overheat. Where sufficient power is not available to take a breakdown test with normal voltage impressed on the armature of the motor, a voltage considerably below normal is used, viz:
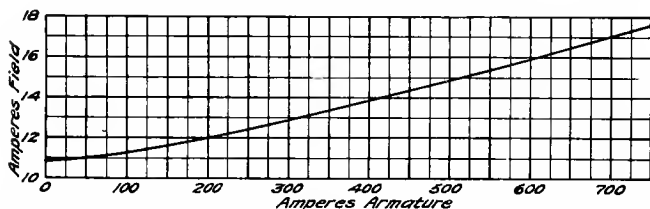
Fig. 39

FIELD COMPOUNDING CURVES ON A 150 KW., 250 VOLT, 225 R.P.M. 6 POLE D.C. GENERATOR (6 BAR BRUSH SHIFT)

$\frac{3}{4}$, $\frac{1}{2}$, or even $\frac{1}{4}$ voltage. It is then necessary to calculate the full voltage results from those obtained at the lower voltages. This may be done by increasing the power output proportionally to the square of the ratio of normal voltage to the lower voltage.

All maximum output tests on synchronous motors, unless stated to the contrary, should be made with a field excitation giving minimum input armature current for a given load. Readings must, therefore, be taken of volts armature, amperes armature, amperes field and volts field with various loads from no load to that load which will cause the motor to break from synchronism, adjusting the field strength for each reading to give minimum input. The speed of a synchronous motor will be constant until the point of breakdown is reached, whereas that of an induction motor will decrease from no load to the breakdown point.

In case sufficient power is not available to make a maximum output test upon a synchronous motor at its normal rated voltage, its voltage may be reduced below normal, as described for Induction Motors. If the minimum input is obtained when

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the readings are taken, the output of the motor at normal voltage may be determined in the manner described for Induction Motors.

The wiring for this test must be arranged so that the armature circuit of the motor can be opened immediately when it breaks from synchronism.

BALANCE OF ROTATING PARTS

Static Balance

Rotating parts are usually balanced by putting them on a shaft and laying the shaft on two parallel rails called balance ways. The balance ways must be carefully leveled and well supported to prevent deflection from the weight of the piece balanced. After the correct amount of balance weight has been determined, a suitably formed piece is made and securely fastened to the inside of the rim, or at a point at the same distance from the center as that at which the temporary weights were supported. The weights should be so fastened that they will not produce a shearing stress on the bolt or other fastening holding them in place. In revolving fields the weight should be placed on the inside of the rim. In this case the bolt has only to keep the weight from falling out when the machine is at rest.

On D.C. armatures pockets are generally provided into which melted lead is poured and hammered into place.

On slow speed machines it is not necessary to get accurate balance, especially on heavy fields. On a 2000 or 3000 kw. field running about 120 r.p.m. an unbalanced weight of 50 lbs. would probably not be noticed. Vertical machines must be more accurately balanced than horizontal ones.

Kinetic Balance

A field with good static balance will not necessarily be in good balance when running. It is often necessary to rebalance a rotor kinetically after the machine is assembled.

To roughly locate the position proper for balancing, hold a pencil or chalk so that the high side of the shaft strikes it as the shaft revolves at normal speed. On a rigid shaft this mark will indicate the heavy side, but on a flexible shaft it will probably show the light side of the rotating part. Put some weight on the side opposite the mark and try again. If the balance is better, the weight is in the proper place and the mark will be found to extend farther around the shaft. If the balance is worse, the weight is on the wrong side. If the mark is found to have moved, weight should be added at the new point. If the mark is found on just the opposite side, too much weight has been added.

The shaft must be straight before any balancing is done. This can be determined by holding a pointer or pencil to the shaft and revolving the shaft slowly. If the pointer touches all points, the shaft is straight and the work of balancing may

proceed. If it does not touch all around, the shaft is sprung and must be straightened before the rotor is balanced. On very heavy rotors it is not possible to balance them statically as a whole, because their weight will press the shaft sufficiently into the ways to prevent the rotor from taking its natural position. In this case the parts are balanced separately as carefully as possible and the whole is afterwards kinetically balanced, if necessary.

OBSERVATIONS AND COMMENTS DURING OPERATION
THE REPORTING AND CORRECTION OF DEFECTS

In all Testing Records a number of questions are given concerning the operation and condition of the machine during the test, which should be intelligently answered by the men conducting the test,

A close watch should be made for undue heating of bearings. While running under load, no bearing should rise more than $40°C$. above the room temperature. In case such a rise occurs, the bearing should be scraped and the test repeated. Any machine showing a bearing temperature rise of $25°$, during an equivalent load run, should have the run continued till bearing temperatures are practically constant, unless the temperature continues to rise rapidly. In any case notes should be made if the bearing temperatures rise above these limits and the matter should be reported to the department office.

A record should be made of any oil throwing or leakage during test, and the matter reported at once. In the case of oil throwing on D.C. machines, the test should be discontinued until the defect is remedied.

End play should be tried both with and without field on the machine. This matter should be recorded on the Record.

Redoweling may be done when the end play is defective. To do this, the frame is moved away from the side toward which the rotor is magnetically drawn. In case the frame cannot be moved enough to correct the end play, owing to insufficient clearance between the holding down bolts and the holes in the stator feet, either the holes may be enlarged or the holding down bolts may be turned smaller in diameter where they go through the feet. This will not weaken the bolt if it is not turned smaller in diameter than the diameter of the bolt at the root of the thread. If a machine is properly leveled the rotor will revolve without rubbing either oil deflector, when there is no field on the machine. If, when field is excited, the rotor pulls parallel to the shaft the field and armature are out of magnetic balance. Either the rotor may be out of place on the shaft, or the frame may not be properly located on the base. Defective end play can be remedied by either moving the rotor on the shaft or the frame on the base. To correct, it is generally advisable to move the frame rather than to move the rotor.

During a heat run, machines set upon shop blocking should have the blocking and holding down bolts examined at least

every 24 hours to prevent the machine pulling over. A load of more than 400 kw. should not be carried by belting unless special permission has been received from the office.

Any connections not checking with the connection print or wiring diagram should be reported.

When the air gap is incorrect, the defect may be remedied by inserting or removing sheet iron shims under the pole pieces or between the frame feet and the base. Before doing this, however, the matter should be referred to the office. All shims should be cut neatly, in order that no change need be made before the shipment of the machine.

All machines should be carefully watched for any unbalancing or change in alignment. A defect of this nature may appear after the machine has been running for some time even though the balance and alignment may have seemed perfect at the beginning of the run.

Record should be made of binding bands, commutator shrink ring or any other part running out of true.

Eccentric commutators or commutators with the mica bridged over by copper, should be reported. Commutators developing loose bars should be baked by the method mentioned in connection with making equivalent load tests on D.C. machines, and the clamping ring tightened at intervals until it cannot be tightened further. After all tests are made, the commutator baked and fittings removed any eccentricity or roughness of surface may be removed by turning. In stoning a commutator, the stone is fastened in a holder made for this purpose. Care should be taken that the direction of rotation of the commutator is away from the operator during the stoning process. The turning and stoning process is never employed if no eccentricity exists and the commutator surface is in good condition during the test.

Commutators sometimes become noisy during operation, due to brush friction. This may be remedied by a slight occassional lubrication of the commutator surface. The noise may be due to the brushes chattering, in which case no lubrication must be used, but the defect reported at once. Chattering may be caused either by poor commutator surface or an improper setting angle of the brushes.

One or two brushes may glow and become very hot on a stud carrying a number of brushes, while the other brushes run cool and without sparking. This is known as selective commutation and is due to difference in brush pressure, composition or contact resistance which cause some of the brushes to carry more than their share of the current, thus overheating them and giving poor commutation. In order to remedy this difficulty, it is usually necessary to change either the brushes or brush pressures, or possibly both.

At the same time that the hot resistances and high potential test is taken, the insulation resistance of the field and armature should be measured. This test must be made on all machines built for the Government, turbo-generators, and the

armatures of A.C. machines having a voltage of 2300 or over. In case it should be lower than required, due to dampness, the machine should be baked either by the method described for making equivalent load tests on large D.C. machines or by placing the machine in a baking oven.

Collector rings with rough joints, eccentric collector rings or ones running out of true should be reported at once to the Department office.

Unless the line circuit of a machine or the circuit supplying excitation to the fields is grounded, grounds developing in the armature, fields or fittings during test may not at once become apparent. During the high potential test any defect of this nature is readily shown, however, and should be reported at once in order that repairs may be made immediately.

The spacing and alignment of field poles, especially in the case of commutating pole machines, should receive the most careful attention. Poor alignment is usually indicated when the air gap is measured. On commutating pole machines, the spacing between the tips of the commutating and main poles must never vary more than $\frac{3}{32}$ in. Any greater variation should receive the attention of the Department office.

The checking of polarity at once indicates the reversal of any field coils.

In three-phase machines the reversal of any phase will cause a considerable unbalancing in the voltage across phases. The reversal of one coil will be shown in a similar manner, but the unbalancing is not so pronounced. In quarter-phase machines these defects will be shown by the phase rotation test only. The test of balancing voltage and current and of phase rotation should, therefore, be carefully taken.

The compounding tests made before the adjustment of the German silver shunt can be used to locate any series spools which may be reversed. After adjusting the shunt field to give normal no-load voltage, full load should be thrown on the machine. The voltage then should rise above the normal no-load voltage. If it does not rise but falls with the speed held constant, the series field is either weak or reversed. If the whole series field opposes the shunt field, it may be easily checked by tracing out the direction of the current after it leaves the armature. All field spools are wound in the same direction, so that only the general direction around the frame need be traced. The series field may be wound in an opposite direction to the shunt field. In this case reverse the series leads.

Should the machine over compound with the series field in the reverse direction from the shunt field the test should be immediately discontinued until the spools are changed. A report of this defect should be made to the Head of Section.

In locating a reversed series spool it is best to excite the series field up to 20 per cent of full load current, then either try for polarity or take a potential curve using the series field as a source of excitation. Extremely low voltage will appear on the potential curve both in front and behind the reversed spool.

During a test, the armature coils of a machine may have become short circuited. If the defect is serious, that portion of the armature will smoke. This, however, does not often
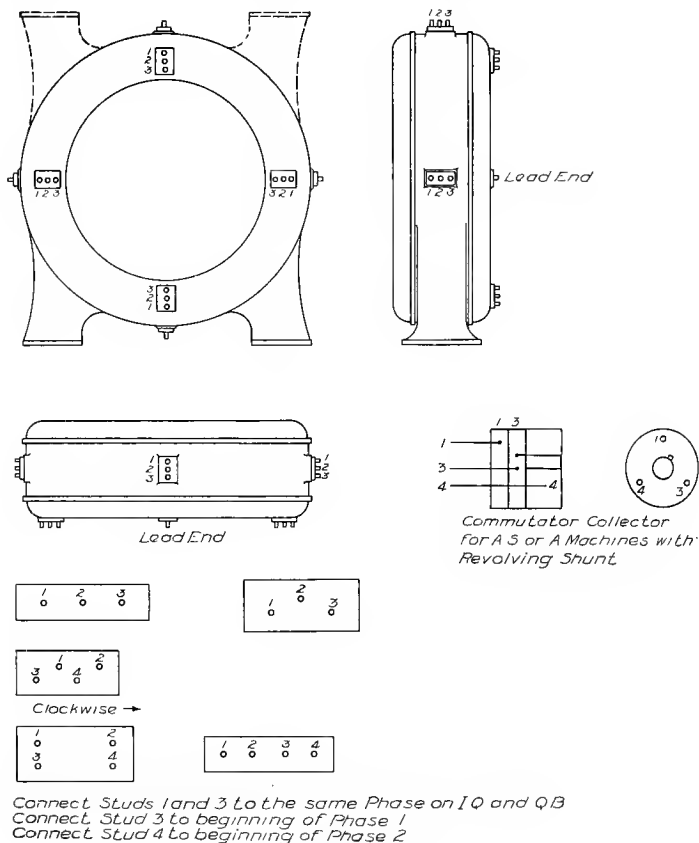

Commutator Collector for A 5 or A Machines with Revolving Shunt

Clockwise →

Connect Studs 1 and 3 to the same Phase on I Q and Q B
Connect Stud 3 to beginning of Phase 1
Connect Stud 4 to beginning of Phase 2

Fig. 40
CONNECTION BLOCKS

occur, hence at the conclusion of a heat run an examination should be made for hot coils. A short circuited armature coil will cause poor commutation on D.C. machines.

A short circuit developing in a field coil of a machine will be shown by changing the field current suddenly or by poor commutation.

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The existence or development of any of these defects must be recorded on the Testing Record and reported to the Head of Section without delay.

In taking phase rotation on A.C. machines a "test motor" should be used. This "test motor" consists of a bar magnet

AQ Machines
With Revolving Shunt

Commutator Collector for
AT Machines Collector Studs
have odd numbers, Commutator
Studs have even numbers
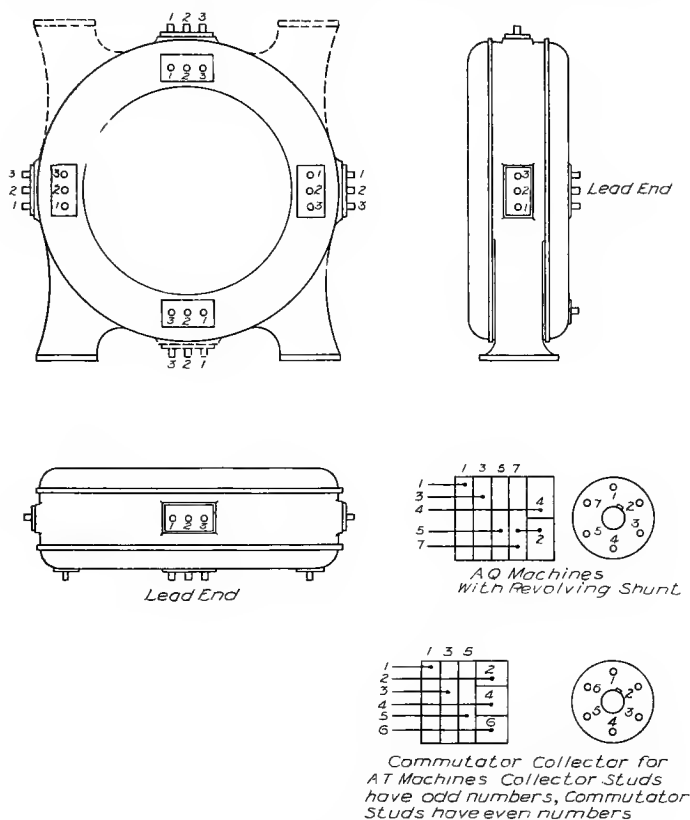
Fig. 41
CONNECTION BLOCKS

revolving inside a core with a ring winding having four taps numbered 1, 2, 3, and 4. See Fig. 10.

In making the test, the terminals of the machine, whether three- or quarter-phase, are connected to the corresponding terminals of the "test motor" Facing the head end of the

machine the bar magnet will rotate in the same direction as the rotor of the machine being tested, if the phase rotation is correct. If it rotates in the opposite direction a phase is reversed for a quarter-phase machine. In the case of a three-phase machine either a phase is reversed or the wrong leads have been brought out. The head end of a machine is the end at which the coil to coil armature connections are always made.

Figs. 40 and 41 cover every type of standard connection block and will assist in numbering the machine terminals for the "test motor." If the block is on the side of the machine facing the bearing, or on the outside of the frame proper and at right angles to the shaft, the numbers should read 1-2-3 in a clockwise direction. If the block is in any other position, as on the side facing the bearing with the numbers running radially, or on the frame proper with the numbering parallel to the shaft, the same sequence of numbers should exist, but the block has been given a quarter turn in a clockwise direction. In the case of revolving armatures the numbering is always from the inside ring toward the outer.

Commutation Tests

The commutation of a machine at all loads should be witnessed by the Head of Section or by one of his assistants; for new machines or those on which commutation is important the Designing Engineers should be present. To obtain good commutation, the brushes on generators are shifted forward, on motors backward, from the mechanical neutral except in the case of commutating pole machines. The brushes of these machines must not be shifted without permission from the office.

Brushes on machines without commutating poles are shifted for full load commutation. This shift must not give a commutation worse than No. 2 at no load. If a poorer commutation is obtained at full load the matter should be reported at once.

DLC (Commutating pole) machines should not give commutation worse than No. 1¼ with 150 per cent. load. Other commutating pole machines should give No. 1 commutation at all loads from no load to full load.

The shifting of brushes on series generators necessitates good judgment. The brushes should first be given a little more lead with full load than is necessary for commutation. The load should then be gradually reduced, and the commutation noted until zero voltage is obtained. Should sparking occur at any point, a readjustment of the brushes should be made by shifting them back towards the neutral point, provided that full load commutation will so allow.

In setting brushes for variable speed motors and in judging for commutation, the brushes should be set to give good commutation with slow speed at no load, and with high speed at full load. Satisfactory commutation at these points insures satisfactory commutation at all intermediate loads and speeds.

Regulation Test—Speed—Voltage

Shunt Regulation should be taken on shunt generators. A reading should be taken first at no-load normal voltage.

Without changing the rheostat, ¼ load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding ¼ load, the voltage should be brought up to normal and the same readings taken. The load should now be increased to ½ full load, with the rheostat in the same position, similar readings being repeated. This test is repeated for ¾ and full load. With full load on the machine the voltage should then be brought up to normal. With the field rheostat in this position the load is then taken off the machine and the rise in voltage observed. All these entries should be made on the Record Sheet. A curve should be plotted with amperes armature as abscissæ and volts as ordinates.

If the voltage should drop to zero when ¼ load is put on the machine, the load should be applied in smaller increments. Speed should always be kept constant throughout the test.

Speed regulation is important in the operation of motors and particularly in the case of D.C. machines. The speed on all motors should be adjusted hot, by shifting the brushes, but should never be corrected at the sacrifice of commutation. It should always be adjusted for full load unless instructions specifically state otherwise.

If special tests are required for a motor, a hot speed curve should be included. Starting from no load to full load, the speed should be carefully read at several intermediate points, the voltage being held constant at all loads. A curve is then plotted with speed as ordinates and amperes as abscissæ. No load and full load points of a cold speed curve should also be taken. Fig. 42 shows the general shape of the curve. Some motors with considerable armature reaction give a speed curve which rises as the load increases.

On a load run, the speed of shunt and commutating pole motors should not vary more than 4 per cent. from normal speed and the regulation must not exceed 6 per cent. During commercial runs, the allowable regulation is 12.5 per cent., and the speed may rise 2 per cent. above or fall 5 per cent. below normal.

When speeding up motors with increasing load, the brushes must never be shifted far enough as to produce sufficient armature reaction to weaken the field. Careless shifting of brushes under load have sometimes caused runaways, hence care is necessary when shifting the brushes.

The speed of railway motors or series motors should never vary more than 3 per cent. from the normal rating.

A test of the voltage regulation of A.C. generators is sometimes made, but more frequently the regulation is calculated from the saturation and synchronous impedance curves. The method of making this calculation is more fully treated under the subject of Alternating Current Generators. In making the test the machine is subjected to normal load with normal .voltage held on the armature. With the same field excitation the load is suddenly thrown off and the armature voltage observed. The difference between this and normal voltage, divided by normal voltage, is the per cent. voltage regulation.

Direct connected exciters should be given a Stability Test. With rated no-load voltage on the alternators, raise and lower the speed 2 per cent. above and below normal, noting and recording the voltage change in each case. The change in voltage should not exceed 6 per cent. of normal no-load voltage in either case. The no-load voltage setting should always be made with a rising field.

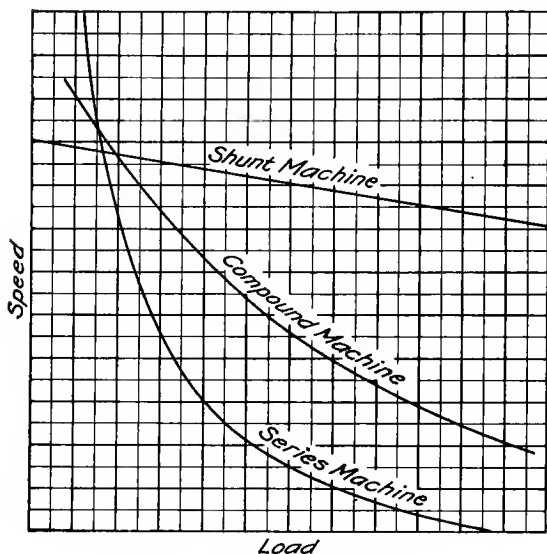When a compound wound generator is compounded hot, a compounding curve should be taken after the German silver

Fig. 42
SPEED CURVES D.C. MOTORS

shunt is properly adjusted. Starting with the no-load voltage readings of volts armature, amperes armature, volts field and amperes field should be taken at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and full load. The load should then be reduced by the same increments to zero, the same readings being taken. A curve should be plotted with amperes line as abscissæ and volts as ordinates. The variation of this curve from a straight line will not usually exceed 5 per cent. If a greater variation occurs it must be reported to the office.

Input Output Tests

It is sometimes required to measure the efficiency of a machine or a motor-generator set by the input output method. The measurement of the power input to the motor and output from the generator is then required. The efficiency of the set will then $= \dfrac{\text{Total output of generator.}}{\text{Total input to motor.}}$

The efficiency of the generator $= \dfrac{\text{Total output of generator.}}{\text{Input to motor—motor losses.}}$

The efficiency of the motor $=$

$$\dfrac{\text{Output of generator and generator losses.}}{\text{Input to motor.}}$$

In the case of induction motors, input output test is sometimes taken by the string brake method which will be discussed more fully under Induction Motors.

The input output method of measuring efficiency is subject to considerable inaccuracy. It is not recommended and should not be used except under special conditions. It is much more preferable to ascertain the losses directly, when reliable results are desired. By adding all the losses to the output at any load, the input for that load may be obtained, which divided into the output gives the per cent. efficiency.

The resulting errors from the input output method are likely to be large, since any inaccuracy in meters or readings influences the results directly. The same per cent. error in meters or meter readings in loss measurement tests, influence the results of the efficiency calculations indirectly. Consequently the latter method is superior for accurate determinations.

Phase Characteristic

In taking phase characteristics to determine the field current for minimum input at a given load on either synchronous motors or rotary converters, the machine must be operated as a motor from some A.C. source of correct frequency and at nearly constant voltage. A reading of amperes input on all phases should be taken with zero field on the motor, where possible. Starting with a weak field and reading volts and amperes armature and volts and amperes field, the field should be increased by small steps until the point of minimum input armature current is found. Increasing the field current beyond this point increases the amperes armature. On a no-load phase characteristic curve, the watts input at the lowest point should check very closely with the sum of the core loss, friction and windage losses, since the power factor is unity on synchronous motors at this point. With a weak field the current is lagging and with a strong field it is leading. In taking a no-load phase characteristic the current should rise to a value of at least 50 per cent. of full load A.C. current.

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A load phase characteristic should be taken in a similar manner to the no-load. The output is held constant and the amperes load recorded in addition to the readings noted above. It is impossible to obtain a zero field point during the full load characteristic, since the current would be so large as to dangerously heat the machine and the torque not sufficient to carry full load output.
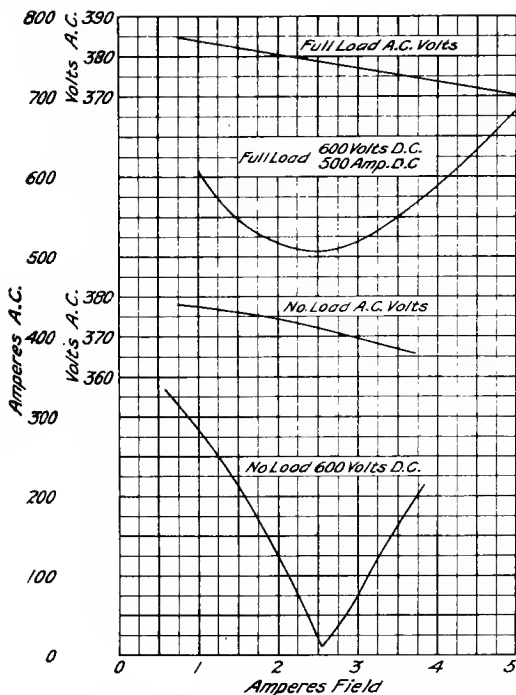

Fig. 43

NO LOAD AND FULL LOAD PHASE CHARACTERISTIC ON A 300 KW. 600 VOLT, 750 R.P.M., 3-PHASE, 25 CYCLE ROTARY CONVERTER

All readings should be corrected for instruments, shunt ratios and a curve plotted between amperes field as abscissæ and amperes armature as ordinates. See Calculating Sheet 6 and Fig. 43.

Synchronous and Static Impedance

Synchronous impedance should be taken on A.C. machines to determine the field current necessary to produce a given

armature current when the machine is running short circuited. Since the regulation of the machine is calculated from the impedance and saturation curves, care should be taken that consistent results are obtained.

The armature should first be short circuited; then with the machine running at normal speed and a weak field current, the current in each phase should be read. The field current should be increased gradually until 200 per cent. normal armature current is reached, readings being taken simultaneously of amperes armature and field and volts field.
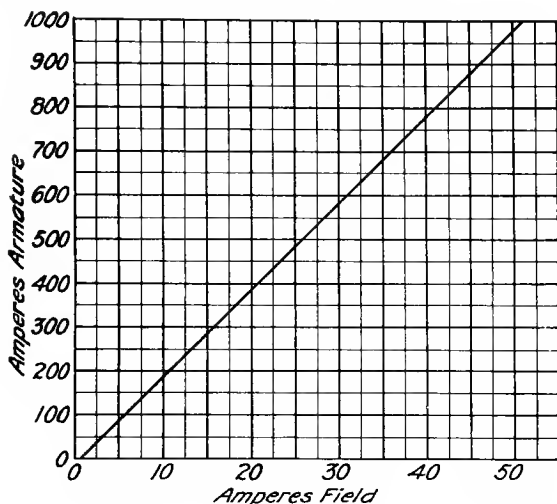
Fig. 44

SYNCHRONOUS IMPEDANCE CURVE ON A 500 KW., 600 VOLT, 360 R.P.M.
3-PHASE, 60 CYCLE, A.C. GENERATOR

Although the speed in this test should be held normal a small variation therefrom will not affect the curve, because in the formula, $\text{current} = \dfrac{\text{e.m.f.}}{\text{Impedance}} = \dfrac{E}{\sqrt{R^2 + L^2 W^2}}$ the term R^2 is small compared with $L^2 W^2$, and as E and W vary proportionally to the speed, the current remains practically constant.

On some of the standard machines, a stationary impedance is taken in addition to the synchronous impedance. First block the armature stationary, then connect the armature leads to an alternator giving the same frequency as the machine being tested. Starting with about 50 per cent. normal current,

the current in the armature of the machine tested is increased by steps to about 150 per cent. normal, readings of volts and amperes armature being recorded.

This method should be followed in taking stationary impedance during the preliminary tests on Induction Motors, except that it is only necessary to take one reading at normal current. A special stationary impedance test is sometimes taken on Induction Motors. This is treated under Induction Motor Tests.

In the calculation of synchronous impedance all readings should be corrected for the constants of instruments and ratios used and a curve plotted on the same sheet as the saturation curve, amperes or ampere turns field being plotted as abscissæ and amperes armature as ordinates. See Calculating Sheet 7 and Fig. 44.

Wave Form—Potential Curve Between Brushes

In the determination of wave form of a D.C. machine the following method should be used: The machine should be run at normal speed and voltage. A pair of voltmeter leads separated a distance equal to the width of one commutator bar, is placed on the commutator under the center of one pole and moved from bar to bar over to the center of the next pole of like polarity, the voltage being read at each step. In this way the voltage between bars is obtained for a complete cycle of 360 electrical degrees.

The readings should be corrected and plotted as ordinates against the number of the corresponding bars as abscissæ and a sketch showing the position of the poles should be made on the same sheet in conjunction with the curve obtained.

Wave form on alternators is obtained by the use of the oscillograph.

Heating Tests

The determination of the heating of a machine is a very important test and great care must be taken to obtain reliable temperatures. Any large machine requiring a considerable amount of floor space should have the room temperatures taken at four different nearby points, and at a sufficient distance away as not to be affected by radiation of heat from the machine. Two thermometers, one in air and one in a specially designed metal cup containing oil, are used at each point to measure the room temperature. Before starting a heat run, thermometers should be placed on the *stationary accessible* parts indicated by the Testing Record. Each thermometer should be attached with the bulb in contact with the part of which the temperature is required, the bulbs being covered with putty. Thermometers which are to register the temperature of air ducts, should be so placed that the bulb cannot make contact with the iron laminations while the machine is running.

The machine should be shielded from currents of air coming from adjacent pulleys and belts. Unreliable temperatures are

obtained when the machine is located so that another machine blows air upon it. A very slight current of air will cause great discrepancies in heating. Consequently either a suitable canvas screen should be used to shield the machine under test, or the machine causing the draught should be shut down.

Overload heat runs require considerable attention. Where an overload is applied for one or two hours, be certain that normal load temperatures have been reached before applying the overload. The overload must be carried only for the specified time, since, in many cases, the temperature rises rapidly throughout the whole period of the overload. Hence, lengthening or shortening the overload period a few minutes may make several degrees difference in the overload temperatures obtained. To avoid continuing an overload run for longer than the specified time, arrangements for a sufficient number of thermometers and resistance measurements must be made well in advance of the end of the run.
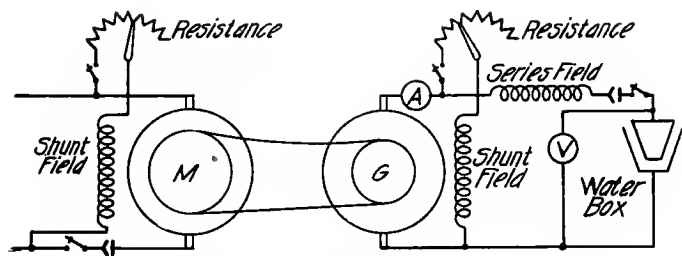
Fig. 45
CONNECTIONS FOR LOADING A D.C. GENERATOR ON A WATER BOX

During the heat run all conditions should remain normal, and the machine should be watched carefully for any undue heating of bearings or field spools or for the appearance of defects. The wiring, holding down bolts, belt lacing, etc., must be watched.

In order to identify the resistance measurement corresponding to a heat run, it is very important that the proper *date* and the time of making the test, *whether A.M or P.M.* should be entered on the Testing Record.

In making heating tests two methods may be used; *i.e.. Actual Load Tests* and *Equivalent Load Tests*. Several different means for obtaining Actual Load Tests may be employed, such as "Water Box," "Circulating," "Feeding Back," "Shifting the Phase" and "Induction Generators."

The "Water Box" method, as the name implies, consists in driving the machine either by a motor or engine and loading it upon a water rheostat or "box." See Fig. 45. This method entails considerable expense, since all the power generated is

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lost. To obviate this loss and reduce the cost of testing, the "Feeding Back" method is used when possible, especially in the case of large D.C. machines or motor generator sets. In this method the total machine losses are supplied either mechanically or electrically from an external source. In the mechanical loss supply method, two machines of the same size and voltage should be belted or direct connected together and driven by a machine large enough to carry the loss of the set. Connections are made as shown in Fig. 46. If the machines have series fields these should be connected to boost one another. Both machines should then be run up as generators and thrown together by closing the switch between them when the voltage across it is zero. The field of the machine to act as motor should then be weakened, which throws load on both machines. The speed is held constant by the loss supply motor. After running at the proper load for the specified time, the heat run should be taken off and tests finished according to standard requirements.
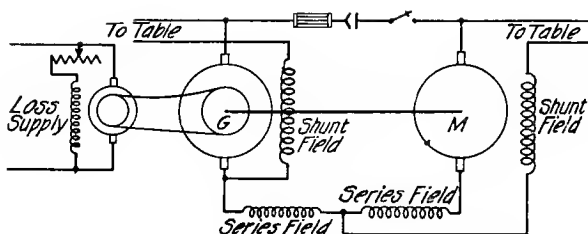
Fig. 46
CONNECTIONS FOR MECHANICAL LOSS SUPPLY PUMP BACK

If the machines are motors, the same connections should be made and the machines thrown together as before. The voltage of the system must be held by the machine running as a generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased and the difference between full load and no load speed will be the normal drop in speed for the motors. Cases have occurred where the speed of the motor, due to armature reaction, increased during the load. In pumping back, this fact is shown by the motor taking an overload at no load speed in which case the speed of the loss supply must be increased.

In the method of electrical loss supply, two machines are direct connected or belted together and the losses supplied electrically. Should two shunt motors be tested by this method, one machine should be run at normal voltage, current, speed and full field; the other motor should be run as a generator

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with a little higher current and slightly stronger field that it would have under normal conditions. The fields of the generator may have to be connected in multiple. Connections should be made as in Fig. 47. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed. After exciting the field of the generator and adjusting the voltage between the machines to zero, the circuit is closed. The machines are loaded by increasing the field current of the generator.

The brushes must always be shifted carefully while the machines are under load, for a slight change in shift will at once change the load. After the heat run has been finished and all motor readings taken, the wiring should be changed and the motor readings taken on the machine which ran as a generator.

When compound wound generators are being tested by this method the series field of the motor must be included or the load will be unstable.
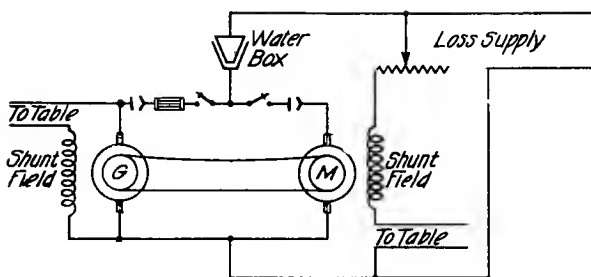
Fig. 47
CONNECTIONS FOR ELECTRICAL LOSS SUPPLY PUMP BACK

Another method of "Feeding Back," often used, is to run the entire load back on the main supply circuit from which the motor is run which drives the generator in test. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of the supply. As changing the line resistances will have no effect at no-load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full-load field current from the no-load current, and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

Two similar motor generator sets can be tested very readily by the "Feeding Back" method.

As an illustration, suppose each set consists of an induction motor and a D.C. generator. In this case connections are made

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as in Fig. 48. The A.C. and D.C. ends of the respective sets are connected together, one set being run normally, and the other inverted. The induction generator feeds back on the induction motor, both taking their exciting current from the alternator (A) which supplies the losses. They are started one at a time from the A.C. end, and the D.C. ends paralleled by means of a voltmeter across switch P. The D.C. motor field is weakened until the ammeter in the D.C. line indicates that normal current is flowing. The weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator while it also decreases the counter e.m f. of the motor a sufficient amount to allow full load current to flow in the D.C. circuit. This load must be closely watched as it is unstable. Load unstability is a rather common occurrence in "Feeding Back," due either to variations in shop voltage or speed.
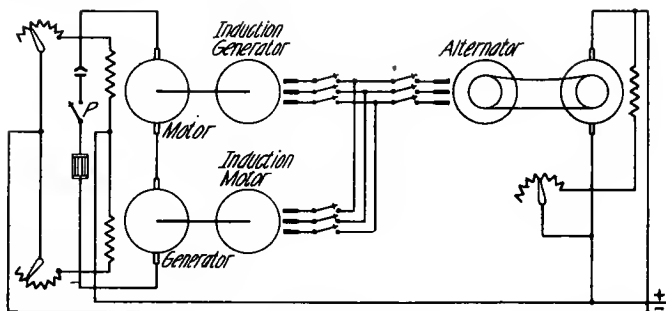
Fig. 48
CONNECTIONS FOR INDUCTION MOTOR GENERATOR SET PUMP BACK

It will be noted in the "Feeding Back" tests described, that it is necessary to weaken or strengthen one of the fields to obtain the load. To conduct the test with the same field excitation on both machines the armature of a separately excited booster may be connected in series with the armatures of the two machines being tested. The machines, connected so that they run at the same speed, are brought up to normal speed by means of the motor supplying the losses. The connecting switch is then closed and the booster field strengthened until normal current flows in the armature circuit, the field current being adjusted to give the same excitation on both fields. The voltage is held across the motor terminals by varying the speed of the loss supply motor. This method, known as the Circulating Method, is used particularly in the testing of series or railway motors. In the latter case the machines are geared to the same shaft.

Another method known as "Shifting the Phase" is used in testing two similar alternators or frequency changer sets. Two similar alternators may be direct connected by means of a coupling and driven by a motor to supply the losses. For example, let a three-phase machine be considered, the phases of which are shown diagrammatically in Fig. 49. The machines should be run at normal speed, the fields connected in series and separately excited to a value corresponding to the load at which it is desired to make the test. The value of this excitation should be calculated from the saturation and synchronous impedance curves. With phases A and A^1 connected together, the voltage across phases b and b^1 is read, the circuit closed,
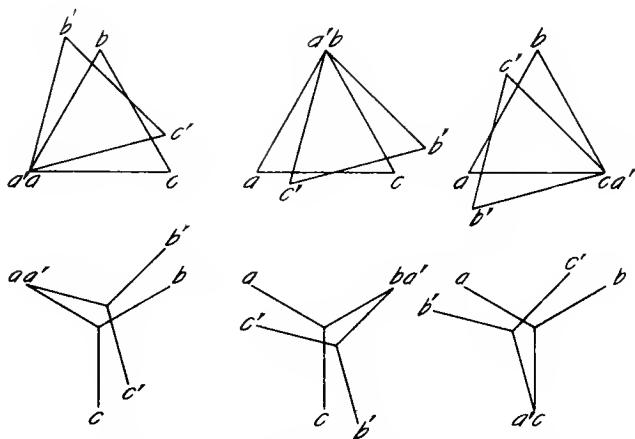
Fig. 49
SHIFTING OF PHASES SHOWN DIAGRAMMATICALLY

and the value of the current flowing observed. Knowing the voltage between phases a and b, a^1 and b^1 and b and b^1, the angle of phase displacement may be readily obtained. Should the armature current be considerably greater or less than that desired, a further trial will be necessary.

The current value will vary nearly as the angle of displacement so that an approximate value of the angle desired can be found from the value of current and angle previously ascertained. When the value of this angle has been ascertained, the phase displacement should be changed, so as to obtain it as closely as possible. With the machines still connected together as they were originally, the angle of phase displacement previously found will be increased

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120 electrical degrees by connecting a^1 b. If a^1 c are connected, a still further displacement of 120 degrees is obtained. If with any of these connections, the field of one machine be reversed, a still further displacement of 180 degrees is made. With the connection which gives the nearest value of armature current to that required, a further adjustment may be made by shimming the stator of either or both machines up on one side and taking shims out on the other side. The circuits should then be closed and the heat run made for the specified time. Even with the angles of phase displacement possible with the various combinations of connections and field reversals it may not be practicable to get the desired armature current. In this case, unbolt the coupling and shift the rotor of one machine around one or more bolt holes. The "cut and try" operation should then be repeated.
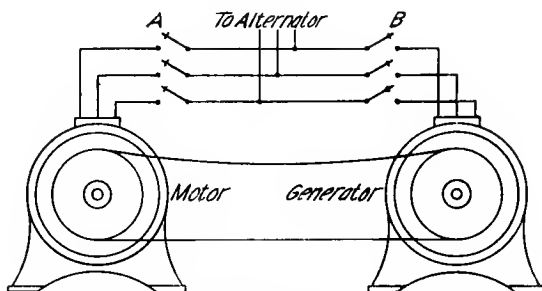
Fig. 50
INDUCTION GENERATOR METHOD OF PUMPING BACK

Although the method employed in this test may seem long and tedious, the results obtained are very satisfactory, especially where it is necessary to make an actual full load test.

The Induction Generator method is sometimes employed in making full load tests on induction motors. Two similar induction motors are belted together and run in parallel from the same alternator which supplies the losses. See Fig. 50. In order to get full load in both machines, the diameter of the pulleys must differ by a percentage equal to double the full load per cent. slip.

In starting, the switches A are closed and the motor M allowed to come up to speed, until the speed of the motor running as a generator is above synchronism. The alternator field is opened momentarily, whilst the switches B are closed. The circuit in the alternator field is then closed again, and full load current flows through the two machines. No changes in load can be made without changing the pulley ratio and it is absolutely necessary that this ratio be correct in order to obtain full load.

Equivalent Load Tests

Very often it is found impossible to run actual load tests, especially on large machines on account of limited facilities. Equivalent load tests have consequently been devised in which the heating of the machine at a certain load may be very closely ascertained without actually loading it. One of five different methods may be employed in making such a test: "Open Circuit," "Short Circuit" and "Low Voltage Test," "Circulating Open Delta" or "Phase Control."

D.C. machines can be satisfactorily tested by short circuiting the armature upon itself or through the series field, connected so that it will not build up as a series generator. The shunt field is separately excited from an external source, until the required current flows through the armature or armature and series field. This method is excellent for baking and settling the commutator. Amperes armature and field, and volts field should be read throughout the run.

In the case of alternators, the machine is run open circuited, with a field current that gives a predetermined percentage over normal voltage. The run should be continued until the rise in temperatures above the room temperature is constant, after which the machine is shut down and the final temperatures taken. The armature is then short circuited, the machine started again, and sufficient excitation given to obtain a given percentage over normal current in the armature. This run also should be continued until the rise in temperatures above that of the room is constant, after which the final temperatures are taken. The resistance of the field should be carefully measured before and after the open circuited run, the armature before and after the short circuited run, the temperatures of the resistances cold being also recorded. During both runs volts and amperes field should be recorded as well as speed. During the open circuit run, volts armature are recorded and amperes armature during the short circuit run. All entries must be made immediately on the Testing Record.

On some of the large induction motors, only about one-fourth of the normal voltage is impressed. The machine is then loaded until the desired current flows in the stator, the run being then continued as described above.

Another method of making an equivalent load test, used especially with turbo and other large three-phase alternators, is known as the Circulating Open Delta run. The phases of the machine are connected in delta, one side of which is left open. The fields are excited to give the load desired, this excitation being determined from the saturation and synchronous impedence curves. Due to harmonics which may exist in the legs of the delta, an A.C. cross current may flow in the winding This is measured by an A.C. ammeter, with current transformer, if necessary, inserted in the opening of the delta. The difference between the square of this current and the square of the current with which it is desired to load the machine is found, and a direct current of a value equal to the square root

of this difference is circulated through the winding. The run is then continued, careful record of volts armature, D.C. and A.C. amperes armature, volts and amperes field being made. It will be noted that the A.C. cross current in one side of the right angled triangle and the D.C. current in the other are combined vectorially to obtain the load current desired.

Another method of loading an A.C. generator is to give it normal excitation and run a synchronous motor light from its armature circuit. The field of the motor is then varied to give a leading or lagging current in the armature circuit. This is known as the method of Phase Control.

The rise in temperature on the fields during an open circuit run and on the armature during the short circuit run is practically the same as will be obtained during operation under load. The rises in temperature obtained from a circulating open delta run are also so considered.

It has been found that the temperatures with low voltage runs made with induction motors, when combined with temperatures at no load at normal voltage, give very nearly the same testing results as an actual load test.

During the heat run on any machine careful readings should be made and regularly recorded on the Testing Record. Any changes in testing conditions should be explained in detail. Especial care should be observed in the reading of thermometers, and all meter numbers, constants, and transformer ratios should be recorded.

Except in the case of commutating pole machines, it is often necessary to shift the brushes to get good commutation of the machine while under load. The point at which the best commutation is obtained is known as the running point. Its position must be plainly marked in both the rocker arm and the frame by means of a chisel, the number of bars shift from the neutral point being recorded on the Testing Record.

It is the present practice to adjust all series field shunts cold, except in cases where a hot compound is expressly desired. In order to insure a consistency in the sizes of German silver shunts for similar machines, the Calculating Room records should be consulted before attempting the compounding of any machine. This compounding consists in placing a shunt across the series field terminals in order to give the proper voltage at no load and full load. The contacts of the shunt should be perfect. In making a no-load field setting on the machine, the voltage should be raised about 15 per cent. above normal no-load voltage, and then reduced to normal. With the rheostat left in this position, the load is thrown on, and if the compounding is high the resistance of the G.S. shunt should be reduced, a new no-load reading taken and the operation repeated. This should be continued until the machine compounds according to specifications. The final length, number of strips and section of German silver used should be recorded on the Testing Record.

To take final temperatures after a heat run requires the greatest care. Arrangements should be made that no delay results in placing the thermometers on the proper parts. Temperature readings should be made every few minutes until all temperatures begin to drop, when the thermometers may be removed. *All temperatures must be recorded immediately upon the Testing Record and never upon scrap paper.* While final temperatures are being taken the hot resistance of the machine should be measured. After all the necessary tests are made, while the machine is still warm, the wiring should be removed and the high potential tests applied.

In calculating the rise of temperature by resistance the following formula is used.

Let Rt_2 = hot resistance of copper measured at the temperature t_2

Rt = cold resistance of copper measured at temperature t_1

Ro = resistance of copper at $0°$ C.

$$t_2 = (238 + t_1) \frac{Rt_2}{Rt_1} - 238$$

By the use of this formula it is assumed that .0042 is the temperature coefficient of copper at $0°$ C. The rise obtained from this formula should be corrected by one-half of one per cent. for each degree C. that the final room temperature differs from $25°$ C. This correction is added if the temperature is below $25°$ C. and subtracted if above it. The temperature of a winding itself must, therefore, be very carefully observed as well as that of the room when the hot and cold resistances are taken.

It is often necessary to make a heat run of an A.C. machine at a specified power factor. To do this, in the case of a generator, the machine is loaded on water boxes connected in parallel with a synchronous motor. The motor merely floats on the line, its field being adjusted to give the desired power factor. Instead of loading the generator on water boxes the motor is often belt or direct connected to a D.C. generator which feeds back into the shop circuit.

Synchronous motors are run under load at a certain power factor by being driven from an A.C. source of power and loaded on a D.C. generator. Generators should always be run with lagging and synchronous motors with leading current when power factor runs are made, unless otherwise specified.

In addition to an ammeter and voltmeter, wattmeters should always be inserted in the armature circuit of the machine tested in order to check up the power factor of the circuit.

Equivalent load heat runs are frequently made at a given power factor. In the case of an open circuit run, the excitation given the machine is a certain percentage over that which will give the desired voltage at the desired power factor and

load. This excitation is determined from saturation and synchronous impedance curves. Short circuit runs are made with a certain percentage of armature current over that required to give the desired k.v.a.

Circulating open delta runs are made as previously described, allowance being made for the proper excitation and armature current at the power factor desired.

D.C. GENERATORS

Preliminary Tests

Preliminary tests on D.C. generators consist in drop on spool, polarity, hot and cold resistance measurements, air gap, potential curve, rheostat data, brush shift, running light and equalizing ring tests. With the exception of potential curve, rheostat data and equalizing ring, the tests have all been previously discussed.

On all multiple wound armatures of self-contained machines, not equipped with equalizing rings, a potential curve must be taken. All the brushes except those on two adjacent studs are raised from the commutator, the voltage is then raised to normal and the field current noted. This field current and the speed must be held constant for all other points on the curve. The brushes on stud No. 3 should now be lowered, those on No. 1 raised and the voltage read between studs No. 2 and No. 3. This should be continued until voltage readings have been taken between each pair of studs. The test should be made with the field current rising. The maximum voltage variation permissible is 4 per cent. of the average value. This test, although similar in name, should not be confused with the bar to bar potential curve taken to determine the wave form of a D.C. machine.

Rheostat data should be taken on all D.C. generators. Unlike the saturation curve, the data is taken with the brushes in the running position instead of at the electrical neutral. Commercial tests on generators consist in taking a reading at one-half normal and normal voltage, amperes field, volts field and volts armature being recorded on a special Record Sheet provided for the purpose. When machines require a heat run, a full curve is taken, carrying the curve to about 10 per cent. above normal voltage. Normal speed must be held throughout the test.

Equalizers consist of rings or cross connections tapping into equi-potential points on the winding of multiple wound armatures between each pair of poles. These rings prevent inequalities in voltage between brushes of equal potential, due to inaccurate centering of the armature. The rings allow alternating currents to flow from the stronger toward the weaker pole pieces, which slightly demagnetize the former and magnetize the latter, thus equalizing the voltage at the brushes. Not only do the rings prevent an interchange of heavy cross currents between brushes, but they also compensate for inequalities in magnetic pull at the pole pieces, tending to bend the shaft or overheat the bearings.

The tester must examine these rings to see that the taps are equally spaced and all connections tight. If a machine has been connected correctly with correct polarity and no open circuits or reversed spools in the field, the machine excitation should build up when the field switch is closed and all resistance is cut out of the field. If it does not, the resistance of the field

should be checked with that of a similar machine of the same size and voltage, as a 500 volt machine may sometimes be assembled with a 250 volt armature. If the field resistance is correct the armature specification should be checked. If the defect still remains undetermined the matter should be reported to the office for further investigation.

While trying to excite a machine the following method will usually remedy the trouble. If the residual flux gives a few volts on the armature with the field switch open, and upon closing the switch the voltage drops to nearly zero, then the current does not flow through the field in the right direction to build up from the residual magnetism. In this case no amount of separate excitation will remedy the difficulty. To remedy, either reverse the field, or shift the brushes over one pole.

Shunt regulation should be taken on shunt generators when requested.

In locating the no-load electrical neutral on commutating pole machines, the fibre brush method is used. A fibre brush, (of which a stock of various sizes is kept) provided with two contacts and terminals separated from one another by a distance equal to one bar, is placed on a brush-holder on one stud. The brush is then shifted until zero voltage is read between the two terminals. The position of the rocker arm is marked at this point. The fibre brush is then placed on the next stud and the brushes shifted again until zero voltage is obtained, this position of the rocker arm also being marked. This is continued on all the studs, the rocker arm being finally set on the mean of the positions previously marked. This setting gives the electrical neutral, it should have the same position at full load.

The shunt in the commutating pole field is then adjusted to give the best commutation at full load, the amount of current shunted through the commutating pole field being measured. The amount of this shunted current must always be recorded on the Testing Record.

The open circuit tests, already described, are sometimes taken on commutating pole generators.

The building up of a series generator is a more complicated operation. The load increases with the voltage and great care must, therefore, be taken in obtaining the correct external resistance to prevent load volts increasing rapidly. As it is practically impossible to decrease the external resistance enough (*i.e.*, put the blade of the water box in far enough) to allow the generator to pick up, the usual method is to put the water box blades in and short circuit one of the boxes with a fuse wire, then close the circuit breaker and switches. If the machine then starts to pick up, and the voltage decreases as soon as the fuse wire burns away there is too much resistance in the water boxes. They should, therefore, be salted (to decrease the resistance) and the operation repeated. Should the resistance in the boxes be too small the load will increase very rapidly, the breakers may have to be opened to prevent the machine arcing over between brushes.

After the brushes are set the German silver shunt should be adjusted to give the required voltage.

A series characteristic is taken on all series wound generators. This is done by increasing the load by small steps until full load is obtained, amperes line and volts machine being recorded at each step. The load is then reduced by small steps to no load, the same readings being taken. A curve is then plotted
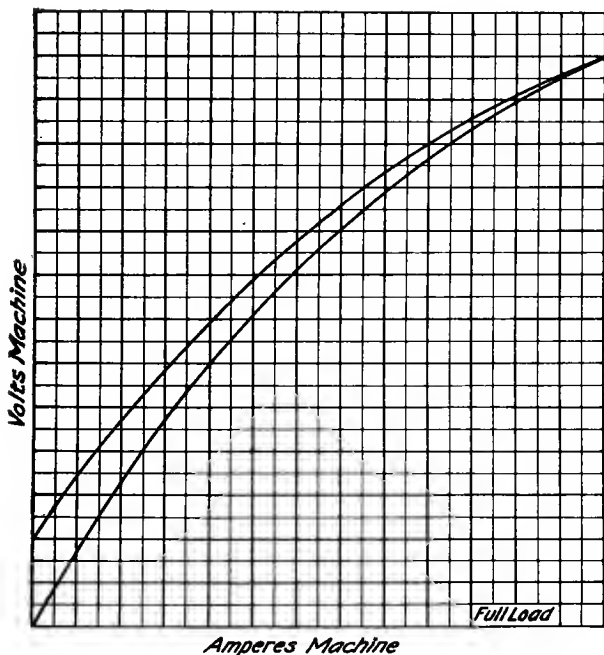

Fig. 51
SERIES CHARACTERISTIC

between amperes as abscissæ and volts machine as ordinates. See Fig. 51.

In the case of series machines forming part of booster sets, the guarantee sometimes does not allow this curve to deviate by more than a certain percentage from a straight line. The curve should be taken in all cases with the German silver shunt in place, if the latter if necessary.

Some D.C. generators are provided with collector rings for three-wire operation. If there are two series fields, one should be connected in each side of the line. All other tests are made as on any D.C. generator. If unbalanced readings are required the compensator should be wired according to diagram. See Fig. 52.

A reading should be taken at no load, normal voltage. With no change in the field and holding constant speed, $\frac{1}{4}$ load should then be thrown one side of the line and the voltage read from the neutral to each side of the line. Volts and amperes line, volts and amperes field should also be read. One-quarter load is then put on the other side of the line, giving a balanced load, readings being taken as before. The load is then increased to $\frac{1}{2}$ load on one side, this procedure being continued until 125 per cent. balanced load is obtained and readings taken at each step. Instructions sometimes call for 50 per cent. unbalancing, in which case the load is increased 50 per cent. at each step instead of 25 per cent.
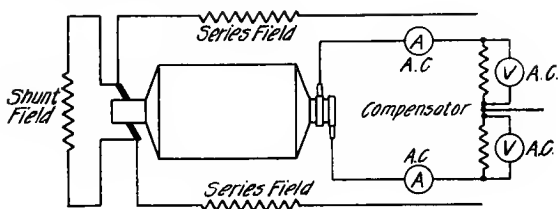
Fig. 52
THREE WIRE GENERATOR

In addition to the preliminary tests, some of the following tests are made on D.C. generators:

COMPLETE TESTS; *viz:* special tests together with normal and overload heat runs.

SPECIAL TESTS; *viz:* saturation, core loss, compounding and commutation tests.

GENERAL TESTS; *viz:* saturation and core loss tests.

NORMAL LOAD HEAT RUN; *viz:* running the machine at normal load until a constant rise in temperature is obtained, all temperatures being recorded. All field adjustments should be made to give the required regulation under the specified load.

OVERLOAD HEAT RUN; *viz:* bringing the machine to normal load temperatures, applying the required overload for the specified time, and recording the temperatures.

SHORT COMMERCIAL TEST; *viz:* operating the machine, if a shunt generator, open circuited at normal voltage for one hour to see that it is an electrical duplicate of similar machines already shipped, and that it is free from manufacturing defects,

A compound wound machine which is not compounded flat (no-load voltage differs from full-load voltage) is run open circuited for one hour at a field current

$$= \frac{\text{Full-load voltage}}{\text{No-load voltage}} \times \text{no load amperes field.}$$

All shunts for series fields must be calculated. Rheostat data should be taken.

Long Commercial Tests consist in running the generator open circuited at normal voltage until temperatures are constant and taking final temperatures. The machine should then be run short circuited at normal armature current, until the temperatures are constant, final temperatures being taken. Saturation and rheostat data should be taken. All series field shunts should be calculated. The remarks already made in reference to field current during the open circuit run on compound wound generators, apply to this test also.

Stationary Commercial Tests consist in checking the air gap and drop on spools and taking ballistic saturation.

Input Output Efficiency Tests are obtained by the input output method, by belting or direct connecting the generator to a driving motor. This test is very seldom used and is not recommended.

Standard Efficiency Test made by the method of losses. The method of calculating efficiency by this method is as follows:

Consider a compound commutating pole generator.

Let V_L = Volts line

I_L = Amperes line = $I_8 + I_9 = I_{10} + I_{11}$

I_6 = Amperes, shunt field

I_4 = Amperes, armature = $I_L + I_6$

I_8 = Amperes, series field = $I_L \dfrac{R_9}{(R_8 + R_9)}$

I_9 = Amperes, German silver shunt = $I_L - I_8$

I_{10} = Amperes, commutating pole field = $I_L \dfrac{R_{11}}{(R_9 + R_{10})}$

I_{11} = Amperes, commutating pole German silver shunt $= I_L - I_{10}$

R_5 = Brush contact resistance

R_6 = Hot resistance of shunt field

R_4 = Hot resistance of armature

R_8 = Hot resistance of series field

R_9 = Hot resistance of series field German silver shunt

R_{10} = Hot resistance of commutating pole field

R_{11} = Hot resistance of commutating pole field German silver shunt

Then total IR drop $= I_4 R_4 + I_4 R_6 + I_8 R_8 + I_9 R_9 + I_{10} R_{10} + I_{11} R_{11}$

W_1 = Core loss watts, taken from the core loss curve corresponding to $V_L + IR$ for each load

W_2 = watts brush friction from core loss test.

If the value taken from test appears inconsistent, calculate W_2 by the formula:

$$W_2 = \frac{F \times N \times B \times L \times \mu \times 746}{33000} \quad \text{where}$$

F = Circumference of commutator in feet
N = R.p.m.
B = Number of brushes
L = Lbs. pressure per brush
μ = Coefficient of brush friction for the particular type of brush used.

In the case of engine-driven machines or those which are furnished without base, shaft or bearings, the bearing friction is omitted from the total losses, and is charged against the prime mover.

In nearly every case it is preferable to use the calculated brush friction instead of that obtained from test. During a short test, the commutator and brush contact surface cannot get into as good condition as obtained after a long period of commercial operation. Consequently, the brush friction test does not represent the conditions that will exist after the machine has been in operation for some time. The coefficient of friction determines the value of brush friction, which in turn is determined by the condition of the commutator and brush contact surface. This coefficient varies considerably at first and only reaches a constant value after a considerable period of operation. The coefficient used in the above formula for the calculation of brush friction has been obtained by the Company by means of exhaustive tests on brushes of different types with various pressures and commutators. These tests extended over a long period to obtain constant and satisfactory conditions for both brush and commutator surface. The resulting values of brush friction can, therefore, be relied on to give accurate and final results.

W_3 = Bearing friction from core loss test
Wb = Watts output = $I_L \times V_L$.
The brush contact resistance, R_5, is that taken from a curve, made for different types of brushes, corresponding to the brush current density per square inch at any given load.

Brush current density per square inch $= \dfrac{I_4}{\frac{1}{2} \text{ total brush area}}$

One-half the total brush area $= \dfrac{l \times w \times s \times t}{2} \quad$ where

l = Length of brush parallel to the shaft
w = Width of brush
s = Number of studs
t = Number of brushes per stud.

For reasons similar to those just given, the Company has made extensive tests to determine the contact resistance of different types of brushes, from which curves have been plotted with brush current densities as abscissæ and either brush contact resistance per square inch or IR drop in brush contact

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as ordinates. In order to measure the contact resistance directly the commutator would have to be short circuited and the voltage drop measured from the commutator to the surface of
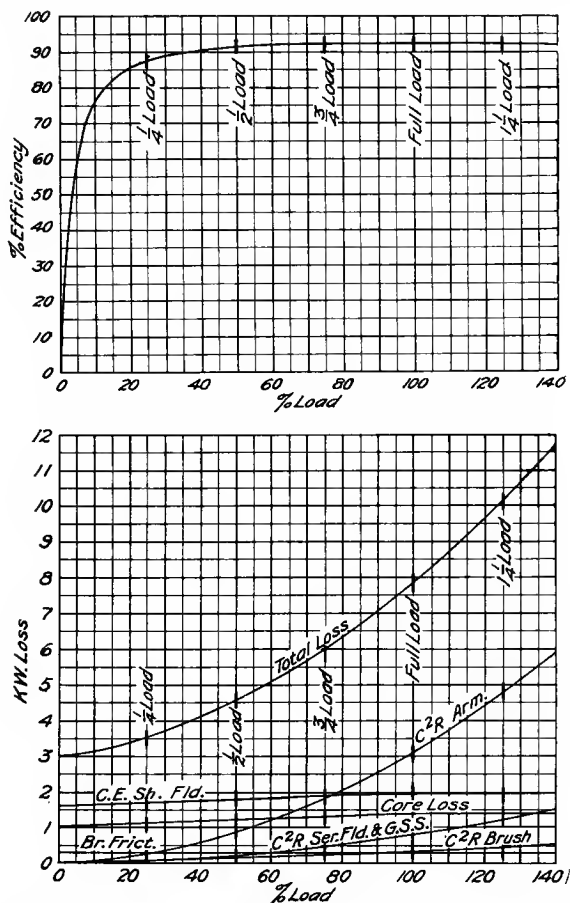

Fig. 53

EFFICIENCY AND LOSSES ON A 100 KW., 6 POLE, 275 R.P.M.
525/575 VOLTS, COMPOUND WOUND D.C. GENERATOR

each brush. This would be a long operation entailing considerable expense. The results also could not be reliable owing

to the newness of commutator and brushes. It is, therefore, preferable to use the brush contact resistance obtained from the curves mentioned.

If $W_3 =$ bearing friction from core loss test, then total loss in watts $= \Sigma W = W_1 + W_2 + W_3 + I_4{}^2 R_4 + I^2{}_4 R s_5 + I_6{}^2 R_6 +$
$(I_6 V_L - I_6{}^2 R_6) + I^2{}_8 R_8 + I_9{}^2 R_9 + I_{10}{}^2 R_{10} + I_{11}{}^2 R_{11.}$

The quantity $I_6 V_L - I_6{}^2 R_6 = I^2 R$ loss in the shunt field rheostats.

The watts input Wa will then be

$$W_a = W_b + \Sigma W, \text{ where } W_b = \text{watts output} = I_L V_L$$

The efficiency $E = \dfrac{W_b}{W_a}$

In case a core loss test is not made, the running light is substituted in the formula for the quantity $(W_1 + W_2 + W_3)$. If the segregation of the losses in the series and commutating pole fields and their respective German silver shunts is not required the resistances R_8 and R_9 may be combined to equal Rs_F, likewise R_{10} and R_{11} to equal Rc_F.

The total losses then will be

$$\Sigma W = \text{Running light} + I_4{}^2 R_4 + I_4{}^2 R_5 + I_6 V_L + I L^2 R s_F + I_L{}^2 R c_F$$

To calculate resistances hot when calculating efficiencies the temperature should be obtained from the formula:

$$T = (K \times \text{rise by thermometer}) + 25^\circ \ C.$$

K is the ratio between the rise in temperature by thermometer and that determined by resistance measurement. Resistance measurements of temperature have been determined by actual tests on a large number of different armatures and fields. For all armatures, or field spools of revolving field machines $K = 1.25$. For stationary ventilated field spools $K = 1.7$. See Calculation Sheet 8 and Fig. 53 for form used in calculating and plotting efficiency.

COMMUTATING POLE GENERATORS

General Notes

The general instructions covering mechanical inspection, measurement of air gaps, drop on spools, etc., applying to all other generators must be followed in testing machines with commutating poles. The function of the commutating pole is to improve commutation and in testing commutation is, therefore, important. .

Pole Spacing

When the spools are first assembled and "cold voltage drop" and polarity are being taken, the spacing of the commutating poles must be checked by measuring the distance between each commutating pole tip and the adjacent main pole tip on each side and at each end of the commutating pole. Any appreciable variation must be corrected at once and a record made of the final spacing. Should a variation

of $\frac{3}{32}$ in. or more be found, which cannot be corrected by the spool assemblers, the Head of Section must be notified at once, and the defect reported to the General Foreman and to the "Defect Clerk" for consideration or correction.

Commutating Poles

The commutating pole produces the necessary flux for neutralizing the effect of armature reaction. It prevents the shifting of the electrical neutral point, between no load and full load, which occurs in direct current machines not equipped with commutating poles. In addition, it aids the current reversals in the armature coils at commutation. To obtain the proper reversal without sparking, with normal load current, requires a definite number of ampere turns. In many cases, fractional turns are required in the commutating field winding. As only whole turns or half turns are possible for mechanical reasons, a shunt is used across the terminals of the commutating field winding. This is adjusted in test, to shunt current in excess of that required. As the electrical neutral does not shift, the brushes are set on the no-load electrical neutral, adjustments made and the rocker arm chisel marked for that setting. As the brushes are on the no-load electrical neutral the machine is sensitive under any condition that would under excite the commutating poles or make them inactive. Such cases may make the neutral shift, causing bad sparking at the brushes or even a flash over, particularly in the case of machines of 500 volts or over.

For instance, consider a 300 kw. 500 volt generator, with a heavy German silver shunt across the terminals of the commutating field winding. If the machine is short circuited, the inductance of the commutating field coils forces the instantaneous heavy overload current through the non-inductive German silver and leaves the commutating field without sufficient excitation to neutralize armature reaction. The electrical neutral immediately shifts and bad commutation results.

To eliminate this trouble, an inductive shunt is used across the terminals of the commutating field winding, which must always be in circuit when the machine in test is under load. If a short circuit occurs, the inductance of this shunt, being greater than that of the commutating field winding, forces the heavy line current through the field winding, and tends to keep the compensation normal for all conditions of load.

Inductive Shunt

An inductive shunt is used on all machines of 500 volts or more. whose normal current is 400 amperes or greater. As a test is required to determine exactly how much current must be shunted from the commutating field, the inductive shunt is designed to have an inductance greater than that of the commutating field winding with ample current carrying capacity and low resistance. Any additional resistance necessary is

obtained by connecting German silver in series with the inductive shunt. The length and resistance of the German silver used is varied till an adjustment is obtained that gives practically perfect commutation throughout the whole load range for which the machine was designed.

Location of Electrical Neutral

After running up a commutating pole machine to normal voltage at no-load, the no-load electrical neutral must be located. To do this, obtain from the instrument room a fibre brush of the same size as the carbon brushes on the generator in test. This fibre brush has two holes drilled through it, each of which will accommodate a No 12 bare wire. The spacing between the holes is equal to the distance between adjacent commutator bars. The wires used must be small enough to move freely through the holes, otherwise they may stick and make poor contact when placed on the commutator, or they will become wedged and bear on the commutator so hard as to score it badly. Remove one carbon brush from its holder and insert the fibre brush in its place, with the two wires in the brush connected to a low reading or a millivoltmeter. With normal volts no-load on the generator, shift the brushes till the millivoltmeter reads zero. The brushes should be shifted till the instrument needle has passed through the zero point, and then back again until the instrument again indicates zero, to make sure that the actual zero has been found. Pencil mark the rocker arm for this shift, then move the fibre brush to each of the other studs successively, shifting the brushes, if necessary, till zero reading is obtained, pencil marking the rocker arm for each stud. If a different shift is required for the neutral of the different studs, shift the brushes to a position which is the mean of all the different positions, and call the Head of Section's attention to the variation so that he can decide whether it must be corrected and to take the proper steps for so doing.

With the brushes set in the mean position and the inductive shunt properly connected put on normal load and note the commutation. If commutation is not practically sparkless at normal load and rated overload, take off the load and field excitation, and connect a German silver shunt across the commutating field terminals. If the machine requires an inductive shunt the German silver and the inductive shunt are connected in series. With the total shunt resistance great enough to shunt not more than 10 per cent. of normal load current, put on full load and note the commutation. Continue changing the length of the German silver and trying the commutation till an adjustment has been obtained which gives the best commutation through the range of load required. Then connect in an ammeter and read and record the number of amperes flowing through the shunt circuit. In case satisfactory commutation cannot be secured, check all wiring, spool assembly, pole and brush spacing, air gap, polarity, spacing of equalizing

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rings, etc. If these are all found to be correct, use the fibre brush again and try the full load neutral of each stud. If an appreciable voltage is obtained between adjacent bars, shift the brushes carefully till zero is obtained, then try readjusting the shunt across the commutating field. With the best shunt adjustment possible, use the fibre brush on each stud, and record observations, making a record of the current shunted and the shift of the brushes from the no-load neutral. If the results are still unsatisfactory, the case must be brought to the attention of the Head of Section for investigation.

If the full-load electrical neutral of one or more studs is found to differ appreciably from that of the other studs, carefully check the commutating pole spacing, brush spacing and air gaps of those poles and studs affecting the neutral in question.

When a final adjustment has been obtained, on any commutating pole machine of 200 kw. or greater, use the fibre brush on each stud and record the results with full load.

In general, shunting current from the commutating field will shift the load neutrals of all studs away from the no-load neutral the same distance. Shunting less current will shift all neutral toward the no-load neutral. All adjustments must be made where possible with the brushes on the no-load neutral, and the brushes must be left permanently in that position unless special permission to shift them has been obtained. The rocker arm of all commutating pole machines must be plainly chisel marked, when the final adjustment has been made. When satisfactory commutation has been obtained, a heavy load should be thrown on and off suddenly and a record made of the resultant commutation and general behavior of the machine. If the machine has an inductive shunt and flashing or violent sparking is produced by throwing a heavy load on and off quickly, try readjusting the air gap of the inductive shunt.

With a given winding on the core, the inductance of the shunt may be varied by changing the gap, and the relative inductance of the shunt and commutating field winding be thus changed. If the current read on the meter in the shunt circuit quickly falls to zero when a heavy load is thrown off by tripping the breaker, and the brushes show sparking, there is too little inductance in the inductive shunt and its air gap should be decreased. The air gap should be adjusted so as to give the minimum sparking when the machine is operating with a highly fluctuating load.

Baking Commutators

To bake the commutator on a commutating pole machine, the brushes must never be shifted under load so as to produce sparking and heating. They must always be shifted at no-load to insure their not being set beyond the safe limit of no-load commutation, thus rendering it possible for the machine to flash over if the load is suddenly removed. In all cases, the

Head of Section or his assistant must be consulted before the brushes on any commutating pole machine are shifted far from the electrical neutral. It must also be remembered that the armature must not be short circuited through the commutating pole winding, when baking a commutator, as in this case the majority of machines will build up as series generators, and the armature current cannot be controlled.

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DIRECT CURRENT MOTORS

The preliminary tests on D.C. motors consist of drop on spools, polarity, resistance measurements, high potential, air gap, potential curve, brush shift, equalizing rings, and running light.

The connections and wiring of all motors should be carefully examined, with particular reference to the field. At starting, the speed of the machine must be carefully followed with a tachometer, and the circuit breaker must be immediately opened if the speed rises above the prescribed limit.

With the starting rheostat or water box in the off position, the terminals of the rheostat or box must be attached across the open main switch, with the circuit breaker closed. The lower terminal should be attached first. The field switch should then be closed and the pole pieces tested with a piece of iron for excitation. The resistance across the main switch can then be gradually cut out and, if the speed is alright, should be entirely cut out and the main switch closed.

If the motor runs above normal speed the wiring should be carefully examined to see that the field is connected across the circuit. The field may sometimes be connected across the main switch; in this case as soon as the starting resistance is all cut out the field current falls rapidly and the motor speeds up excessively. To test for wrong connection, read volts field during starting; if the field is wrongly connected, the volts field will drop as the starting rheostat is cut out.

If a potential curve cannot be taken on a motor, with a multiple wound armature, by running it as a generator a "Motor Potential Curve" may be taken by the following method: The machine is run as a motor with the field self-excited, the field current held constant, and a constant voltage applied to the armature, using only two adjacent sets of brushes on the commutator. A careful reading of the speed is then taken under these conditions. The brushes on the next pair of studs should be placed on the commutator, and the speed again taken with the same voltage and field current as before. This should be repeated for all pairs of adjacent brushes. The speed should vary directly with the voltage if a potential curve is taken as described for a direct current generator. This method should never be employed unless it is impossible to drive the machine as a generator, as it is very difficult to read the tachometer sufficiently accurately.

With no load, normal voltage and full field, a speed reading is taken, the brushes being shifted so that when full load is on, the speed is not less than 5 per cent. below or more than 2 per cent. above normal speed.

At the end of the speed run the machine is loaded, the brushes shifted if necessary and the commutation noted.

On the compound wound motors, a shunt is adjusted across the series field to give a speed within 4 per cent. of the correct speed at the rated load. Speed curves and running light should be taken with the series field disconnected.

Running light should be taken at hot full load speed.

COMMUTATING POLE MOTORS

The electrical neutral on *commutating* pole motors is determined by shifting the brushes until the same speed is obtained in both directions with the same field, this position of the rocker arm being marked. The neutral should be obtained at the high speed in double speed motors of this type.

Machines sometimes hunt with full commutating pole field, thus preventing the location of the neutral being obtained. In this case shunt the field slightly, even if commutation is affected. Good commutation is rarely obtained in the unstable condition.

In testing the motors sent out as single units, of which the direction of rotation is not yet known, the electrical neutral is located by shifting the brushes at no-load, till a position is found which will give the same speed in both directions of rotation. The fibre brush method should not be used. To do this test quickly, reversing switches are used in the series and shunt field circuits. Care must be taken, when shifting the brushes, to avoid raising the speed more than 10 per cent. above the rated speed, this being the limit used in the Testing Department.

When the proper no-load shift has been found, with full commutating field, put on normal load and note the commutation and speed. If the speed has increased under load or the commutation is not sparkless, use a German silver shunt across the commutating field and adjust it for commutation, noting the speed on each change in the shunt to make sure the speed is decreasing under load. When the final shunt adjustment is obtained, take a speed curve reading, recording the speed and commutation in both directions of rotation, at no-load, full load and whatever overload is required. At the conclusion of all tests required, and while the machine is hot take a hot speed curve covering the same range of load as used in the cold curve. In the case of two-speed machines, this curve should be taken at both speeds. Additional no-load and full-load readings should be taken at full field. If a falling or constant speed is obtained and commutation is satisfactory, no shunt is necessary, otherwise a shunt must be placed across the commutating field and adjusted to give these speeds.

Running light should be taken at full load hot speed with the commutating pole field disconnected. In the case of two speed machines the running light is taken at both rated speeds, (*i.e.*, full load speeds).

The current shunted from the commutating pole field should, in every case, be recorded.

Tests on compound commutating pole motors are made in a similar manner to those on shunt motors. Running light should be taken with both the series and commutating pole fields disconnected.

Quite frequently commutating pole machines are sent out as part of a motor-generator set, and required to operate

as either motor or generator. All such machines must have shunt adjustments made for both methods of operation while the machine is in test. Since the brushes are set on the no-load electrical neutral on almost all machines the same shift is proper for both motor and generator operation. The majority of machines, however, require a different adjustment of the commutating field shunt, for motor operation, to insure the proper speed characteristic. On the majority of commutating pole motors too strong a commutating field will cause the speed to increase as the load increases. This is never permissible. Current must be shunted from the commutating field till the speed at full load and overload is less than that of no-load, giving the motor speed a drooping characteristic, even though shunting this current may impair the commutation.

If a drooping characteristic and good commutation cannot be obtained with the same adjustment, notify the Head of Section at once, so that the proper steps may be taken to correct the trouble. Inductive shunts are used on both motors and generators, and the adjustment of the shunt is obtained in the same way in each case. In adjusting the commutating field shunt of a motor, however, the speed must be carefully noted, as well as the commutation after any change in the shunt is made.

VARIABLE SPEED MOTORS

The variations in speed of variable speed motors may be obtained by either armature or field control.

Two methods of armature control may be used. The first consists in varying the resistance in the armature circuit and is used in work requiring no inherent regulation or constant load. The economy and inherent regulation by this method of control is poor.

The second method of armature control consists in varying the voltage impressed on the motor armature only, the field remaining constant at its full value. The efficiency and regulation obtained by this method of control is good.

In the method of field control the brushes are set to give the best commutation at both speed limits. The variations in speed are then obtained by varying the field.

Commutating pole variable speed motors must have the shunt in the commutating pole field adjusted for the highest rated speed. Speed curves and running light tests should be made at both speed limits.

Shunt wound variable speed motors have the brushes set for commutation at the speed limits. Speed curves and running light tests should be made at both these speeds.

Some compound wound variable speed motors are not designed to run light, consequently before starting, the smallest load the motor is designed to carry should be ascertained. The Engineering Notice usually specifies the load at which the motor should start. Commutation should be adjusted at the speed limits, series full field readings being taken and the

speed carefully recorded. Speed curves should be taken at the speed limits. Running light should be taken at the various speeds, with the series field disconnected.

The following tests may be taken in addition to the preliminary:

COMPLETE TESTS:

Consist of special tests and normal and overload heat runs.

SPECIAL TESTS consist of saturation, core loss, speed curves, regulation and commutation tests, also variable speed tests on variable speed motors.

GENERAL TESTS consist of saturation and core loss tests.

INPUT OUTPUT EFFICIENCY is made by the input output method, either by direct connecting or belting the machine to another machine or by using the string brake method.

STANDARD EFFICIENCY TESTS are made by the method of losses.

Using the same nomenclature as that used in calculating the standard efficiency of D.C. generators, a motor efficiency is calculated as follows:

$I_4 = I_L - I_6$

Watts Input $W_a = I_L V_L$

$W_1 =$ Core loss taken from the core loss curve corresponding to $V_L - IR$

Then $\Sigma W = W_1 + W_2 + W_3 + I^2_4 R_4 + I^2_4 R_5 + I^2_6 K_6 +$
$(I_6 V_L - I^2_6 R_6) + I^2_8 R_8 + I^2_9 R_9 + I^2_{10} R_{10} + I^2_{11} R_{11}$
as before

Watts output $W_b = W_a - \Sigma W$ and

$E = \dfrac{W_b}{W_a}$

Since motors are always rated according to horse-power output

$H.P. = \dfrac{W_b}{746}$

If, as in the case of D.C. generators, only a running light is taken and it is desired to combine the resistances of the series and commutating pole fields with their respective shunts and to combine the losses in the shunt field and rheostats, then

$\Sigma W =$ Running light $+ I^2_4 R_4 + I^2_4 R_5 + I_6 V_L + I^2_L R_{SFa} + I^2_L R_{CF}$

In the case of shunt motors

$\Sigma W =$ Running light $+ I^2_4 R_4 + I^2_4 R_5 + I_6 V_L$

The remarks made under the subject of D.C. generators in reference to the calculation of brush friction and brush contact resistance, also in reference to the calculation of hot resistances, as well as to *all other* efficiency calculations, apply here. (See Calculation Sheet 9.)

It will be seen from Fig. 54 that motor efficiencies are plotted against amperes line as abscissæ and per cent efficiency and

h.p. output as ordinates. The horse-power curve should be produced to intersect the abscissæ line at running light *amperes line*.
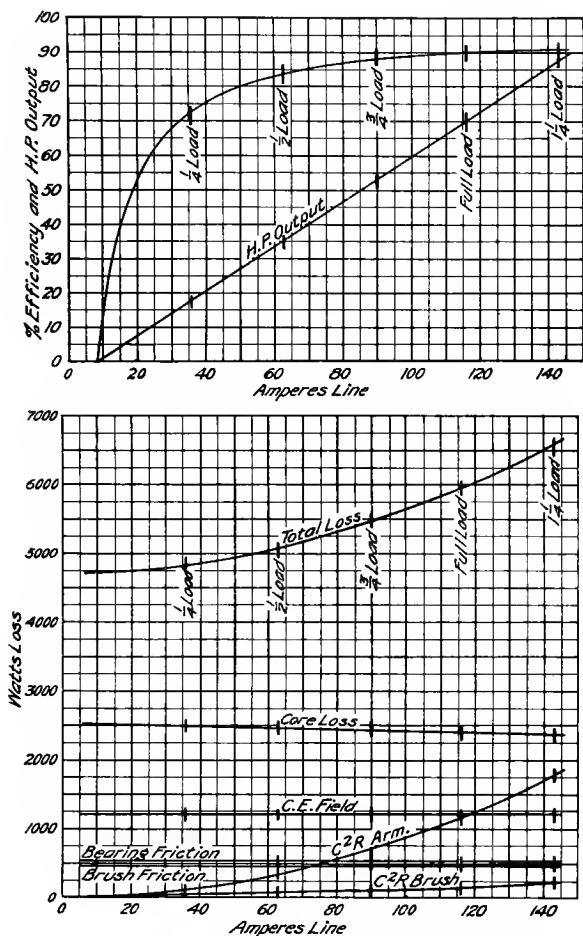
Fig. 54

EFFICIENCY AND LOSSES ON A 70 H.P., 6 POLE, 850 R.P.M., 500 VOLT D.C. MOTOR

NORMAL LOAD HEAT RUN consists in running the machine under load until it has reached constant temperatures and then

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recording them. All series field shunt adjustments must be made to give the required regulation at the specified load.

OVERLOAD HEAT RUN consists in first bringing the machine to normal load temperatures and then applying the required overload for the specified time and recording the temperatures.

SHORT COMMERCIAL TEST consists in running the machine light for one hour normal voltage. All shunts for series fields are calculated.

LONG COMMERCIAL RUN consists in running the machine light until constant temperatures are obtained. All series field shunts are calculated.

DIRECT CURRENT SERIES AND RAILWAY MOTORS

The principal type of series motor is the railway motor. Other types, however, are built for use with hoists, air compressors, pumps, etc. As all these motors are designed for intermittent service the test, unless otherwise specified in the Engineering Notice, are of one hour's duration at full load, the brushes being on the neutral point. The load must *never* be taken off a series motor unless the armature circuit is first opened, otherwise the motor will run away. For the same reason a series motor should always be started under load. All running light tests must, therefore, be made with the field separately excited.

As the tests on railway motors are very complete and their general method applies to any series motor, the tests on railway motors will be discussed more or less in detail. Hot and cold resistances must be taken on all railway motors. The cold resistances, when corrected to 25° C., must not vary more than 5 per cent. from the standard resistance.

High potential must always be applied while the motor is cold and hot. There are Standing Instructions specifying the degree of high potential to be applied to all parts, and for the different types of motors.

General Tests consist of sufficient preliminary tests to warrant engineering approval for production. It is impossible to define, definitely, the heading, since the tests may include only a few minor tests, or they may include Complete and Special Tests. For instance, it may be necessary to make slight changes, either in the construction or design of a standard motor in order that it may meet special requirements due to peculiar operating conditions, etc. After these changes have been made, tests are conducted to insure the motor meeting such conditions satisfactorily. These tests are included under the general tests. If, after completion, they are found to be satisfactory, engineering approval is given for the production of the machine in question.

Complete Tests consist of special tests, thermal characteristics, commutation and input output. With the exception of

commutation, the other tests under this heading will be considered separately.

Cominutating tests on series railway motors should be made by holding normal voltage and operating the machine at loads varying from $33\frac{1}{3}$ per cent. to 200 per cent. normal load.

On series commutating pole motors, Interruption Tests are taken. These consist in opening and closing the motor circuit while the machine is running at various loads and speeds.
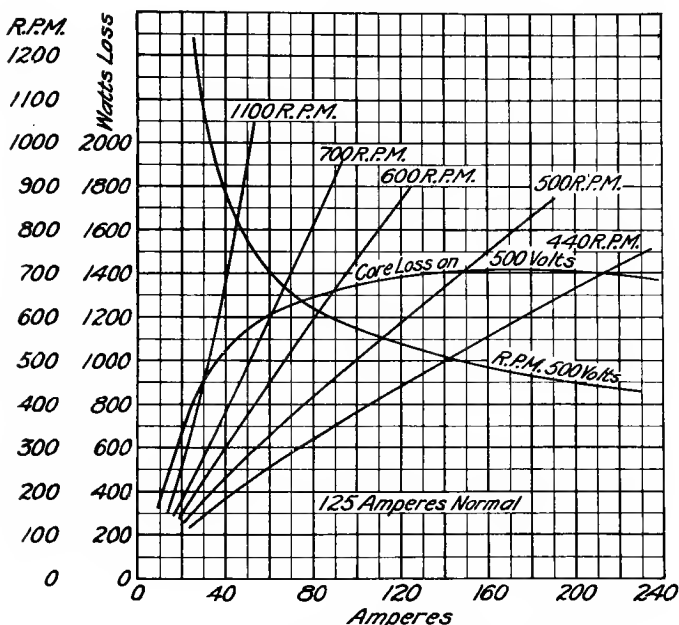

Fig. 55
CORE LOSS AND SPEED CURVE OF A 50 H.P., 500 VOLT
RAILWAY MOTOR

The machine should stand such tests without arcing over at line voltage as high as 125 per cent. normal. The loads are varied from $33\frac{1}{3}$ per cent. to 200 per cent. normal. Mill motors are tested for commutation by suddenly reversing the direction of rotation under various loads.

Development Tests consist of General Tests and Special Tests, and are made when an entirely new type of machine is being developed.

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Special Tests consist of speed curves, core loss, and saturation tests.

In taking a speed curve two similar motors are mounted on a testing stand, the pinion of each meshing in the same gear on a shaft. One motor drives the other as separately excited generator and is run loaded until the motor is heated to about 50° C. rise. The speed curve is then taken on the motor rotating in both directions, the voltage being held constant. The resistance of both armature and field should be measured both before and after taking the curve.

Core loss should be taken as on any other machine by the belted method, except that the test should be made at about five speeds. Fig. 55. The lowest speed should correspond to about 175 per cent. full load amperes (taken from speed curves) and the highest at about 200 per cent. full load speed. During this test the machine is separately excited.

A saturation curve may be taken as on any other machine by separately exciting the field. Saturation curves at different speeds may be obtained from data taken during the core loss test.

The speed curves, core losses and saturation are calculated as previously explained. The speed curves and core losses should be plotted on the same sheet against amperes line as abscissæ and r.p.m. and watts as ordinates. From these two sets of curves another can be developed, which will give the core loss of the motor at any speed or current.

The Thermal Characteristic should be obtained by making a series of heat runs at varying amperes, allowing sufficient time to get a temperature rise of 75° C. on any part except commutator. Each run should be made at the same constant voltage, the current value for each run varying from 50 to 150 per cent. normal. If a sufficient number of heat runs be taken on a sufficient number of motors of the same class, type and form, the horse-power rating for 75° C. rise may be obtained for any length of run from one-half hour to continuous running. Before starting a heat run, cold resistances and temperatures should be taken. After the motor has run continuously for the allotted time, amperes and volts having been held constant with all covers off, and all openings unrestricted, it is shut down, hot resistances measured, and all temperatures taken. The results of the thermal heat run should be plotted, one curve for armature and one for field, against time in hours as abscissæ and degree C. rise as ordinates. Through zero and the plotted points corresponding to the different loads, lines should be drawn. The intersections of these lines with the line of 75° C. rise gives the time the motor takes to attain 75 degrees rise with the load corresponding to the plotted point through which the line was drawn. From these curves another curve should be plotted with time as abscissæ and amperes load as ordinates. This is an ampere time curve for 75° C. rise. On the same sheet as the ampere time curve is plotted, a curve should be drawn

with time as abscissæ and horse-power as ordinates, the horse-power being calculated from the standard 75° C. characteristics. See Fig. 56 for curve.
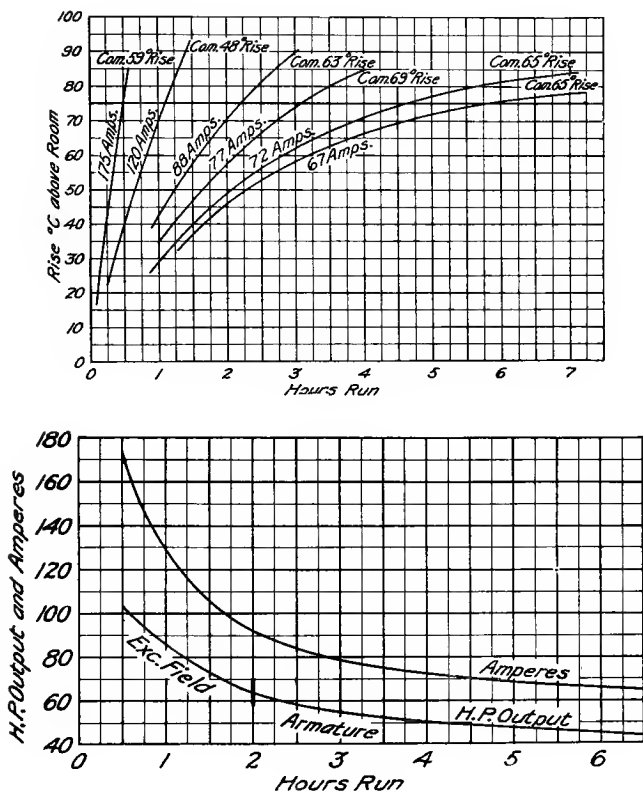

Fig. 56

THERMAL CHARACTERISTICS OF A 75 H.P., 600/1200 VOLT RAILWAY MOTOR

In taking a Load Running Test, as in the Speed Curve, two motors are geared together on the same shaft (see Fig. 57), one running as a motor at the rated voltage and full load current and driving the other as a separately excited generator. The

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separately excited field of the generator is in series with the motor field, thus giving a normal full load excitation. The armature of the generator is connected to a water box, the resistance of which is varied until full load on the motor is obtained. The run is made for one hour, after which temperatures are taken.

Resistances are measured and high potential applied both before and after the test, and, before starting, the speed should be checked in both directions of rotation.

One out of every fifty of all types of motors should receive the one hour load run. All 600 volt commutating pole motors, excepting those receiving the one hour load run, should be run
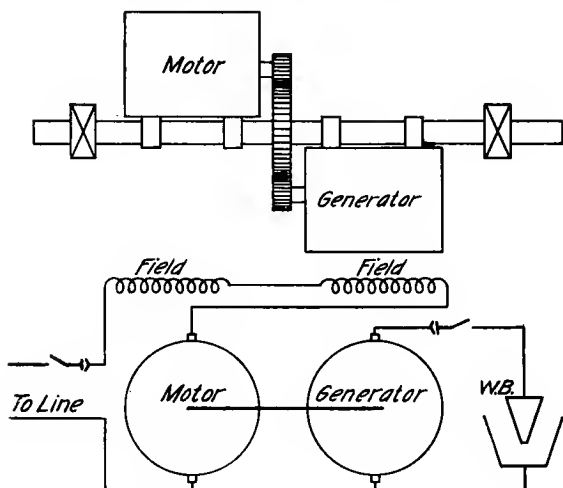
Fig. 57
CONNECTIONS FOR LOAD RUNNING TEST ON RAILWAY MOTORS

under load for ten minutes in each direction of rotation. Other motors having their characteristics well established should receive commercial tests.

Commerical tests consist in running a motor light for a short period. It is the practice to run four motors in parallel, the fields being connected in series and separately excited by a current equal to full load current of the motor. (See Sketch of Connections in Fig. 58.)

With normal voltage held constant across the armatures, the motors are run light for five minutes in each direction of rotation, readings of speed, armature and field current being recorded.

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With rated voltage across the motors, the fields should be weakened until about twice normal speed is attained. Under these conditions the machine should be run in each direction for five minutes, the same readings as above being recorded.

Resistance measurements cold only are taken. High potential tests must be made after this run.

Care must be taken that the resistance at 25 degrees C. and speed come within the prescribed limits already mentioned.

On all series motors *with the exception of railway motors* Standard Efficiency tests are made by the method of losses and the calculation of the same is identical with that of any other motor. In this case, of course, the amperes armature equals amperes line.
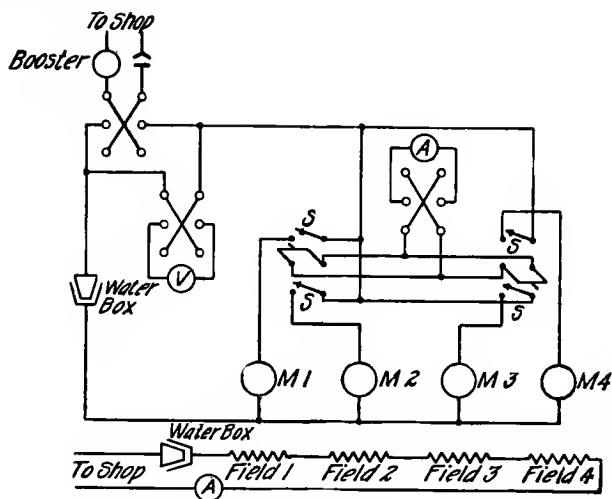
Fig. 58
CONNECTIONS FOR RUNNING LIGHT ON RAILWAY MOTORS

In making an Input Output Test the motors are geared and connected as for the Load Heat Run and are usually run under full load for one hour up to ordinary working temperatures and to get the bearings in good running condition. Before the load is put on, a careful measurement of the armature and field resistance of motor, and armature of generator is taken by the drop in potential method. Three different measurements of each should be made with as many different values of current, which should be near the normal load current.

Holding constant normal voltage, 12 or 15 different loads ranging from as low as possible to 150 per cent. load should

be put on, the direction of rotation being such that the motor tends to lift from its bearings. Readings at each load should be taken of the amperes, volts armature and speed of the motor and amperes and volts armature of the generator. The direction of rotation should then be changed and several check points taken in speed and amperes, after which the machine should be shut down and hot resistance measurements made.

The Calculation Sheet 10 and Fig. 59 show the method of working and plotting the data obtained from the input output test. Unless otherwise specified the tractive effort and miles per hour are calculated for 33 in. wheels. The formulæ used are:

$$\text{Miles per hour} = \frac{\text{R.p.m.} \times \text{diameter of wheels in inches} \times \pi}{\text{Gear Ratio} \times 1056}$$

$$\text{Tractive effort} = \frac{\text{Amps.} \times \text{volts} \times \text{efficiency} \times 252}{\text{Miles per hour} \times 500}$$
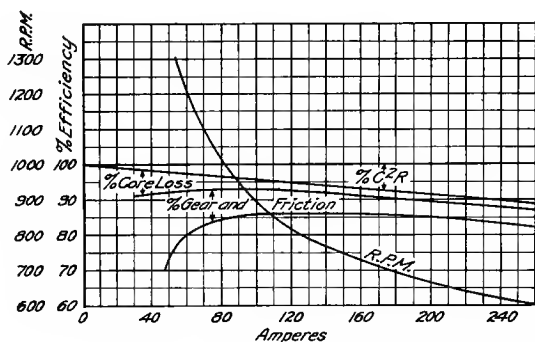
Fig. 59

INPUT OUTPUT CURVES ON A 75 H.P., 600 VOLT, RAILWAY MOTOR

The gear ratio is that between the gear and pinion.

From these characteristics new ones should be plotted, as shown in Fig. 60, the I^2R being corrected for 75° C. rise, and the gear loss assumed as 5 per cent. at full load. If the gear loss from test has to be changed at full load, it should be changed in the same ratio throughout the curve. (See Calculation Sheet 10A.)

Cooling off tests are made by running the motor under full load, with covers off, for one hour, shutting down and reading temperatures as the machine cools down. For the first hour after the machine is shut down, the following temperatures are read every fifteen minutes; the armature, commutator, field, frame, air in the motor, and room temperatures. After the first hour temperatures should be taken every half hour

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until the temperature of the hottest point is not more than 25 degrees C. above the surrounding atmosphere.

The results of the cooling off test should be plotted to time as abscissæ and degree C. rise as ordinates. The curves for armature, field, commutator, frame, air in the motor, should all be plotted on one curve sheet.
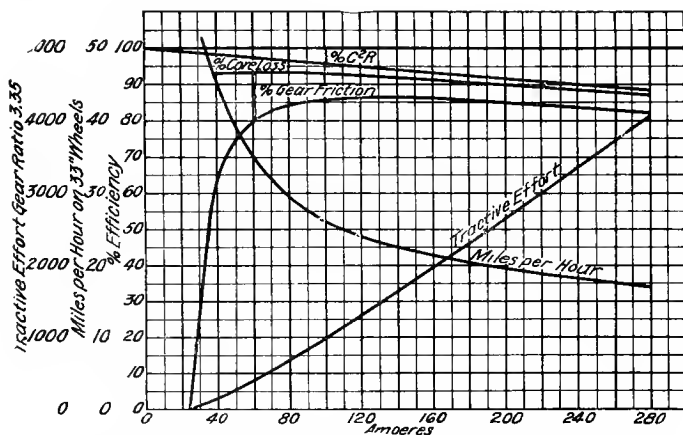
Fig. 60
SPEED, TRACTIVE EFFORT, EFFICIENCY ON A 75 H.P., 600 VOLT RAILWAY MOTOR

ROTARY CONVERTERS

Preliminary Tests

As soon as the spools are assembled on the frame of a rotary converter, the cold drop on each spool is measured and the polarity of each pole determined and permanently recorded in a book furnished for that purpose. These tests should receive particular attention since, though any error discovered is easily corrected at the time, much labor and expense would be incurred if discovered after the machine was assembled complete.

The cold resistance, of the armature winding, is measured between the different collector rings. On a three-phase armature measure between 1–2, 1–3, 2–3. The resistances of these three circuits should be practically the same. On a quarter-phase armature, measure between 1–3 and 2–4, *i.e.*, the terminals of the two phases, which would be of equal resistance. On a six-phase armature measure between rings 1–4, 2–5, 3–6. The resistance should be the same in each case. It is immaterial whether the rings are numbered from the inside or from the outside, for cold resistance measurements.

High Potential

The high potential test is applied at the conclusion of all tests. All temporary wiring must be removed and any dust and dirt blown out by using compressed air, before applying the high potential.

Air Gap

The air gap measurements are made on rotaries, as on all D.C. machines. Special attention must be paid to the gap of a rotary, since it is possible for the bridges on the pole pieces to project beyond the face of the pole. In this case the gap measured between the bridge and the armature is the effective gap of the machine. All bridges must be closely examined for projecting portions, and the gap between the projections and the armature measured and recorded as defects if it is less than the normal gap of the machine.

Running Light

Running light on a rotary is taken with the machine running from the direct current end. With the brushes set on the neutral point, hold the direct current voltage applied to the armature constant, and vary the shunt field till the rated speed of the machine is obtained. Read the input to both field and armature.

Brush Shift

Since very little armature reaction is found in a rotary, the brushes are set on the neutral point, before the machine

is started. It often happens, however, that better commutation can be secured by shifting the brushes away from the neutral point, very slightly. In case of unsatisfactory commutation try shifting the brushes in each direction, since some machines will require a shift forward and some back from the mechanical neutral.

Ratio

Taking the ratio of the A.C. to the D.C. volts is one of the important tests on a rotary. In taking this, care should be taken to insure accurate results. The rotary may be driven from the A.C. or the D.C. end, so long as a definite statement is entered on the record sheet, telling which method was used. In order to check the accuracy of the instruments, two A.C. voltmeters, two potential transformers, and two D.C. voltmeters should always be used. During the test the D.C. voltage is held constant, and the A.C. volts read between rings 1–3 on two-phase and 1–4 on a six-phase machine.

The ratio is taken at no load and full load, and should be as follows when taken with the machine running from the A.C. end:

	No load	Full load
With continuous current .	100	100
Single-phase	71.5	73
Two-phase (measured on diameter)	71.5	73
Three-phase . .	61	62.5
Six-phase (measured on diameter) .	71.5	73
Six-phase (measured on adjacent ring)	35.8	36.5
Six-phase (measured on alternate rings	61	62.5

The amount of pole face arc will change the ratio. Any variation from these values greater than 2 per cent. must be brought to the notice of the Head of Section, so that it may be investigated, and referred to the engineers.

An easy and approximately correct method of telling whether a rotary is running with the proper shunt field excitation is to note the ratio of the A.C. current to the direct current. This should be as follows:

Three-phase alternating current and direct current practically the same.

Two-phase alternating current equal to three-quarters of the direct current.

Six-phase alternating current equal to one-half the direct current.

Equalizer Taps

As soon as a rotary is assembled and before any running tests have been started, the spacing of the equalizer taps and the taps to the collector rings must be carefully checked. Occasionally, a wrong connection is made, and, if it is not corrected before the running tests are started, one or more equalizer leads may become badly overheated or be burned off,

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damaging the armature winding and delaying the shipment of the machine.

Constant Ratio

The standard shunt wound rotary converter has a very nearly constant ratio of A.C. to D.C. volts, so any fluctuation in the A.C. supply shows directly on the D.C. voltage delivered. Such machines are unsatisfactory when much variation in load occurs. When the D.C. volts have to be varied on a standard machine, the impressed A.C. volts must be altered. This is generally done by using transformers with a dial switch, which changes the transformer ratio.

By adding a series field winding to the standard machine, if required to operate with sudden changes in load, a practically constant voltage can be obtained, either by introducing reactance into the circuit or by using the inductance and resistance inherent in its feeder circuit. This is possible since an alternating current passing over an inductive circuit will decrease the potential if lagging and increase it if leading.

A rotary running as a synchronous motor requires a certain field excitation to give the minimum input current to the armature. Varying the excitation either way changes the input current, so, by using sufficient reactance in the A.C. circuit from which the converter receives its power, the A.C. voltage at the converter terminals may be increased or decreased by increasing or decreasing the exciting current. By adjusting the shunt excitation of the compound wound machine so it gives a no load lagging current of about 25 per cent. of full load current, and adjusting the series field to give a slightly leading current at full load, the impressed voltage at no load will be lowered and that of full load increased, automatically. Hence a practically constant D.C. voltage will be delivered at all loads.

SPLIT POLE MACHINES

Variable Ratio

The split pole rotary differs from the ordinary rotary, since it has a split field. The poles consist of two separate and independent parts, each equipped with its own field coil. The auxiliary poles may be placed on either the leading or the trailing side of the main fields, according to the conditions under which the machine is to operate. If it operates as a straight rotary, the auxiliary pole is on the trailing side; while if the machine is to float on the line to take fluctuations of load through a storage battery, and hence runs inverted part of the time, the auxiliary pole will be on the leading side. The following is the reason: The auxiliary pole influences commutation when on the leading side as well as regulating the D.C. voltage. It will be of correct polarity for commutation if the machine inverts at a D.C. voltage corresponding to no excitation of the auxiliary poles.

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In wiring a split pole rotary for test, the transformers must be exactly alike. The best results are obtained by using machines operated from two secondaries excited by one primary. Care should be taken to see that none of the cables from the transformers to the rings differ in length or cross section. All switches in these circuits must have their contact surfaces well cleaned with sandpaper. These precautions are necessary to prevent any unbalancing of the current in the A.C. circuits outside the armature. The testing instructions will include, besides the regular tests made: The manner in which the transformers are to be connected, both primary and secondary; the A.C. volts to be held across corresponding rings, and the range through which the D.C. volts are to be varied by means of the auxiliary field. In addition to the cold resistance, cold drop, polarity and air gap measurements, the following no load readings are taken:

Current per phase (must be balanced).

No load phase characteristic.

Ratio of voltage.

Volts between adjacent collector rings with main field only.

A set of readings of the A.C. amperes, varying the D.C. volts by the auxiliary fields through the total voltage range, holding the main field at minimum input value, the A.C. volts constant with the brushes shifted to give the best commutation over the whole range.

A set of readings, varying the D.C. volts through the total range by means of the auxiliary field, varying the main field to give minimum input for each change in D.C. voltage.

A full load ratio and the current per phase for minimum input, using main field only.

Three full load phase characteristics should be taken:

1st. Hold the A.C. volts constant, using the main field only.

2nd. At the lowest limit of the D.C. volts, holding the the A.C. and D.C. volts constant, the D.C. line current being at that value which gives the rated output for the mid voltage with zero auxiliary field.

3rd. At the highest limit of the D.C. volts holding the A.C. and D.C. volts constant, the D.C. line current being at that value necessary to give the rated output for the mid voltage with zero auxiliary field.

Three core loss tests are required to cover the various conditions of operation:

1st. Core loss varying the D.C. volts by means of the main field only, with auxiliary field not excited.

2nd. Core loss holding the excitation of the main field constant at that value which gives mid D.C. voltage, varying the auxiliary field to change the D.C. voltage.

3rd. Core loss holding the A.C. volts constant. Vary the main field each time the auxiliary field is changed to change the D.C. volts throughout the range.

This gives unity power factor.

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All other tests are made as on standard rotaries, and all general observations, referring to standard machines also apply.

INVERTED ROTARIES

The speed of a rotary, running from the A.C. side, is determined by the line frequency. The same machine running as an inverted rotary and delivering A.C. current operates as a D.C. motor. Its speed depends upon the field excitation and load, and it will deliver a variable frequency, particularly if compound wound. When run inverted, a compound wound machine should have its series field almost, if not entirely, short circuited, when part of its load is inductive, since a lagging A.C. current will weaken the field and increase the speed, sometimes causing a runaway. For this reason, care must always be taken when running a rotary inverted, to see that sufficient field excitation has been obtained to prevent excessive speed, particularly when another machine is operated as a rotary from the inverted machine.

MOTOR CONVERTER

A motor converter consists of a standard rotary converter and an induction motor. The induction motor has a wound rotor with taps brought out to a set of common rings, that take the place of the collector rings for both motor and converter. The voltage of the induction motor rotor is the A.C. voltage of the converter. The advantage of the motor converter is that high tension (up to 13000 volts) may be applied on the stator of the induction motor, the rotor delivering low voltage to the converter. Hence the intervening bank of transformers always necessary with a rotary are not required. No reduction of power factor is caused by the induction motor, since unity power factor may be maintained with the motor converter by proper adjustment of the field of the rotary.

Complete Tests

Complete tests consist of the following:
Cold drop on spools.
Polarity test.
Cold resistance of the armature.
Checking spacing of equalizer and collector ring taps.
Air gap measurement.
Brush spacing and fit.
Hot Armature and Field Resistances, as follows:
Run under normal load till all temperatures are constant. Shut down and take temperatures and measure the hot resistance of the armature and field. Run up again to normal load temperatures, then put on the required overload for the specified time. Shut down, take temperatures and measure hot resistance of the armature and field.
No load ratio.
Full load ratio.
· No load phase characteristic.

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Full load phase characteristic.
Saturation.
Core loss.
Synchronous impedance.
A.C. starting tests.
D.C. starting tests.
Running light reading, D.C.
Check end play.
Phase rotation.
Adjust speed limiting device.
Apply high potential.

Special Tests

Special tests include:
No load phase characteristic.
Full load phase characteristic.
No load ratio.
Full load ratio.
Saturation.
Core loss.
Synchronous impedance.
D.C. starting tests.
A.C. starting tests.

Starting Tests from the A.C. End

The rotary should be wired to an A.C. generator of sufficient capacity to start it without overloading. If transformers are needed, in order to get the correct voltage, they should be placed between the dynamometer board and the generator.

Rotaries at starting from the A.C. end are similar to a transformer. The armature corresponds to the primary, and the field, having a large number of turns, corresponds to the secondary. Hence the induced volts on the field may be very high (often 3000 or 4000 volts). In all cases, therefore, the field connection must be broken in two or more places to keep this voltage within safe limits. A potential transformer and voltmeter should be connected across one or two spools in series, for reading the induced volts field, and a note made on the record sheet as to the number of poles included in the reading.

Starting tests should be made from several different positions of the armature with respect to the field. A scale, corresponding to the distance between collector ring taps, should be laid off on the armature, divided into five equal parts. A point of reference is marked on the field, opposite to which the marked positions of the armature are placed for the successive starts. These positions should be numbered and a sketch showing the numbering be made on the Record Sheet.

Having brought point No. 1 opposite the reference point, the A.C. switches should be closed and a moderate field put on the alternator, sending about one-half normal full load current through the rotary. Read volts and amperes in the various phases. As it will be impracticable to read all phases

at once during the start, cut the ammeter into that phase which shows the highest current and the voltmeter across the phase which indicates the highest voltage, so as to get the maximum readings at the instant of starting. Increase the field of the generator until the armature begins to revolve, when volts and amperes input and induced volts on the field should be read. The voltage across the collector rings should then be held constant, until the rotary reaches synchronism, the time required to reach this point from the start being noted.

There are several methods of determining whether the rotary is in synchronism. One is, the induced volts field will fall to zero; another, the voltmeter across the armature will read a definite voltage, which would vary from a negative to a positive reading if the rotary were below synchronism.

Readings should be taken on all phases, of volts and amperes after the rotary has reached synchronism. The machine should then be shut down, the armature brought to position No. 2 and the test repeated. In this manner all five points should be taken. After these tests have been taken, the time required to bring the rotary to synchronism should be taken by throwing one-half voltage across the collector rings.

Starting Tests from D.C. End

In the case of starting from the D.C. end, the rotary must be wired to a D.C. generator of ample capacity.

When ready to begin the test, the rotary should be separately excited with a field current corresponding to that for no load at minimum input, unless full field is specified. The voltage across the armature should be brought up gradually, by increasing the field on the driving generator, until the armature begins to revolve. The voltage should then be steadily increased at a rate which will bring the rotary to normal speed in approximately one minute. This rate can be found by trial, and, when once found, the test should be repeated once or twice to make certain the results are correct.

Phase Characteristics

1. *No Load.* If the phase characteristic tests follow a heat run on which an IRT regulator has been used, it must be disconnected. The most satisfactory combination is to run two converters for this test, the one under test running as a rotary driven by the other one running inverted with a D.C. loss supply. The speed is held constant by varying the speed of the inverted machine, the D.C. volts being held constant by the volts of the loss supply. It must be remembered that a lagging current will increase the speed of the inverted rotary. The speed of the inverted machine should be watched constantly, so long as the current lags.

With the field excitation of the rotary reduced to the lowest limit permitted by the inverted machine, read the A.C amperes and volts and the D.C. amperes and volts field. The speed and the D.C. volts are held constant throughout the test. Increase

the field current of the rotary, by small increments, reading as above. The A.C. amperes input will decrease rapidly till the minimum input point is reached when they will increase again. The field excitation should be increased till they have a value of at least half the full load current of the machine.

2. *Full Load*. The full load characteristic is taken in exactly the same way as the no load. The D.C. volts are held constant at normal rating and the amperes output constant at full load value. The field excitation is varied through as nearly the same range used on no load, as is possible. The readings taken are:

    A.C. volts.
    A.C. amperes.
    D.C. volts (held constant).
    D.C. amperes output (held constant).
    D.C. volts field.
    D.C. amperes field.
    Speed held constant.

Compounding Test with Reactance

When a rotary is required to automatically deliver a constant D.C. voltage, with a load subject to sudden changes, a compound wound machine is used with a definite reactance inserted between the rotary and the line. Such reactances must be tested with the machines for which they are designed. A constant voltage is possible, since an A.C. current passing through a reactance will increase the potential if leading, and decrease it if lagging. By adjusting the shunt field so that about 20 per cent. lagging current flows at no load and the current at full load leads slightly, the strength of the series field can be adjusted so as to give a constant D.C. voltage. A compound converter, running with reactance, must be compounded like a direct current generator. Unless other specific instructions are issued in reference to compounding, hold constant the A.C. voltage of the alternator by which the rotary is driven. Adjust the shunt field to give the correct no load voltage, then, without touching the field rheostats, put on full load and read the D.C. volts. If the machine over-compounds, the series field is too great, and gives too much leading current. In this case a shunt must be adjusted across the terminals of the series winding to shunt a portion of the current. On this compounding test, all readings are taken and adjustments made as on a direct current generator without touching the field rheostats after the no load adjustment is made.

Pulsation Bridges

Since the torque of a rotary need only be great enough to overcome that due to its own losses, it is very sensitive to changes in line conditions, *viz*, excessive line drop or speed changes of the driving unit. Line drop alone will start a rotary pulsating, in many cases. Once started the pulsation generally

increases rapidly, till the rotary falls out of step or flashes over. To prevent pulsation, copper or brass bridges are located between the poles, which act as a short circuited secondary and oppose sudden changes of the input armature current. Rotaries of new design are tested for pulsation by inserting a resistance per phase, between them and the driving alternator. The drop through this resistance corresponds to the line drop which will probably occur in practice. Usually 15 per cent. drop is used, the resistance per phase necessary being easily determined by using the formula $\dfrac{(A.C. \text{ voltage})^2}{Kw. \times 1000} \times$ per cent. drop = resistance. If two rotaries are tested together each machine would have 15 per cent. drop between it and the driving alternator or there would be 30 per cent. between the two rotaries, as shown in Fig. 61.
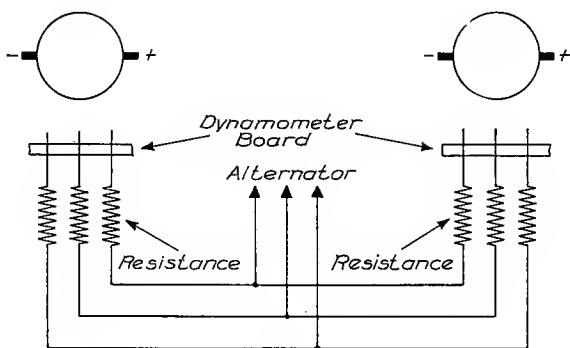
Fig. 61
CONNECTIONS FOR PULSATION TEST

With the two machines running in synchronism self-excited and with the fields adjusted to give minimum input, observe the D.C. voltmeter on the two machines. Any slight pulsation will be shown by these instruments at once. Hold the D.C. volts constant on one machine throughout the test. With one field held at minimum input value, reduce the field current in the other machine to about one-half minimum input value. If no pulsation is noted, take a full set of readings on both machines, then reduce the field current of the other machine to one-half minimum input value, and watch for pulsation on both machines which now take a heavy lagging current. Take a full set of readings under these conditions. Next adjust the field of the first machine again to the minimum input value, watch for pulsation and take readings. With this field held at

minimum input, change the field of the other machine from its value at one-half minimum input to twice the minimum input value, observe and read. The other field is then brought up to twice normal value, readings are taken and the effect of the heavy leading current in each machine noted. Leaving one field over excited, weaken the other field so as to get half minimum input, look for pulsation and take a full set of readings. If no pulsation develops with the high line drop under these extreme conditions, the machines are satisfactory.

General Tests

General tests will consist of:
No load ratio.
Saturation.
Core loss.

Input Output Efficiency Test

Input output tests on small machines (300 kw. or less) are made with the machine running as a rotary, dead loaded on a water rheostat. Larger machines are tested in pairs, one machine pumping back on the other with electrical loss supply. The machines are wired exactly in a similar manner to that used in a pump back heat run (circulating power heat test) special attention being given the wiring to see that no unbalancing occurs on either the A.C. or the D.C. circuits. On the machine running as a rotary, wattmeters are connected in the A.C. end, between the rotary and the transformers, and preparation made for reading D.C. armature and field current and volts. If current transformers are used with the wattmeters, duplicate transformers must be used in the other phases of the machine to prevent unbalancing caused by the resistance and inductance of the transformers. With the machine running in synchronism at rated speed with zero load, and all meters connected, hold the A.C. volts impressed on the rotary constant and take careful readings of all instruments. Then read the current and volts in each phase, as a check on the wiring and balancing of all phases. Also carefully check all instruments for stray field. Any instruments so affected must be protected by iron shields or their location changed. With full load, repeat the test for stray field, since any instrument affected will give misleading and erroneous results. With the no load minimum input field current held constant, carefully read the A.C. input, as shown by the wattmeters, as a check on the no load losses.

As efficiency is usually guaranteed at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$ and $1\frac{1}{2}$, careful readings must be taken at these loads. Each time the load is changed, the rotary field excitation must be changed to the minimum input value for that load which is shown when the sum of the wattmeter readings is exactly equal to the k.v.a. input. To obtain this condition every time, usually requires several trials and considerable time, so that an efficiency test made in this way is more expensive than when made by

the separate loss method. The likelihood of error is also greater. This method, therefore, is not satisfactory for rotary efficiencies at other than full load.

Standard Efficiency

The method employed to calculate the efficiency of a standard rotary converter is similar to that used for D.C. generators except for the additional I^2R and friction losses of the A.C. brushes. Because of the neutralizing action of the motor and generator currents it should be noted that only a certain percentage of the current as given by the instruments must be used for calculating the I^2R loss in the armature. This percentage varies for different machines as follows:

Single-phase	147%
Two-phase	39%
Three-phase	59%
Six-phase	27%
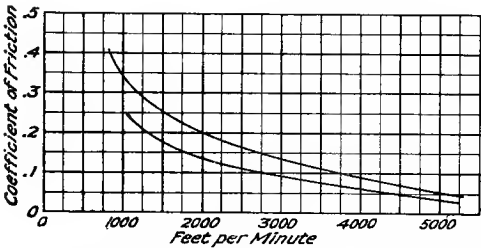
Fig. 62
*COEFFICIENT OF FRICTION OF A.C. BRUSHES

The calculation of the A.C. brush contact resistance requires a measurement of the A.C. current flowing in the armature. This also varies in different types of machines. The following are the constants by which the D.C. current should be multiplied to obtain the A.C. current.

For Single-phase	1.41
Two-phase	.707
Three-phase	.943
Six-phase	.472

As with the D.C. brush contact resistance, a curve must be referred to of the A.C. contact resistance. This should be used and no direct measurement of resistance attempted. In every case the contact resistance should be calculated per ring, the total loss being obtained by multiplying by the number of rings.

Brush contact area per ring = width of brush in inches × arc of contact in inches × the number of brushes.

* Upper curve taken with copper collector rings. Lower curve taken with gun metal collector rings.

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The brush density per ring = $\dfrac{\text{A.C. current}}{\text{Brush contact area per ring}}$

The resistance obtained from the curve, corresponding to this value divided by the brush area per ring is the contact resistance per ring.
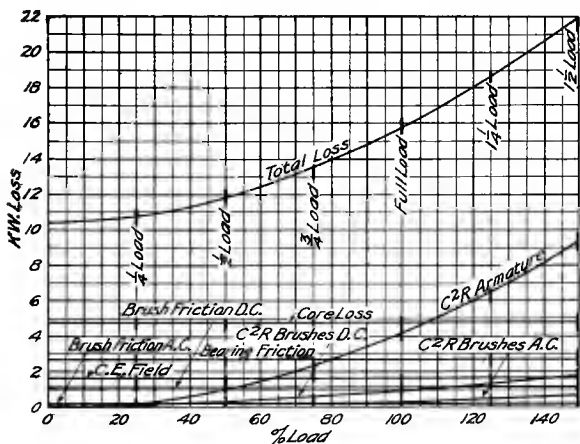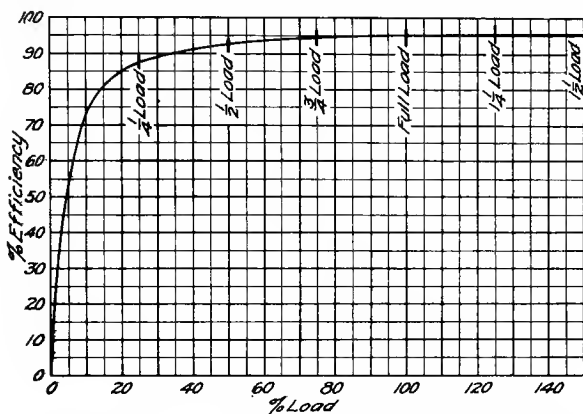
Fig. 63

EFFICIENCY AND LOSSES ON A 750 KW., 600 VOLT, 750 R.P.M. 25 CYCLE, 3-PHASE ROTARY CONVERTER

The A.C. brush friction should be calculated in the same manner as used for D.C. measurements, the coefficient of friction being taken from a curve. See Fig. 62.

Calculation Sheet 11 and Fig. 63 show the form used in calculating and plotting rotary converter efficiency.

Normal Load Heat Runs

When loading a rotary converter on a water rheostat, see that all cables from the transformers to dynamometer boards and to the A.C. rings of the machine are of the same length and capacity. All contacts must be cleaned and brightened before connection. Equal resistance will thus be obtained per phase and unbalancing in the A.C. circuits external to the armature prevented. In wiring the D.C. circuit the series field and its shunt are disconnected.

- In wiring rotaries, as with all other high current D.C. machines, both sides of the circuit should be laid close to one another. No iron, such as a bearing pedestal or a section of the frame, must lie within the loop of the circuit, since it will become magnetized and materially affect the operation of the machine and instruments. Always divide the shunt field into at least four sections, by a "break up switch." This switch must always be open while starting from the A.C. end, since, due to transformer action and relative number of turns of the field and armature, a high voltage is induced in the field at starting.

Always wire the positive brush ring of the rotary through a breaker to the blade of the water box, and the negative ring to the box of the water resistance. Connect enough boxes in multiple so that each will carry about 400 amperes, maximum. Make provision for reading amperes and volts armature A.C., amperes and volts armature, amperes and volts field D.C., and the speed of the alternator.

To start the machine close the A.C. line switches and the field switch of the driving alternator. Increase the excitation of the alternator, keeping close watch on the current in the A.C. lines. If this current reaches 150 per cent. normal before the rotary starts, check over the wiring and report to the Head of Section. If the machine starts rotating in the wrong direction, reverse two of the leads on the primary side of the transformers. After starting, as soon as the A.C. current drops to the minimum value, showing the machine is in synchronism, and the A.C. volts are normal, close the field "break up switch." If, after closing the shunt field switch, the brushes begin to spark, the residual magnetism left in the poles by the induced voltage at starting is of the wrong polarity.

Two methods can be used to correct this: 1st. Reverse the field with respect to the armature. 2nd. Reverse the residual polarity, by opening the alternator field circuit. Then close this circuit and bring the rotary back to synchronism, repeating the operation if necessary, until the field builds up in the right direction. This second method is the more satisfactory since no change of wiring is required.

Before proceeding further, read the current in each phase to make sure there is no unbalancing. These currents should not vary over 1 per cent. from the average; any greater variations due to wiring must be remedied at once.

After balance is established, the no load and full load phase characteristics are taken.

These operations complete the preliminary tests and the full load heat run may now be made, taking care to set the brushes for the best commutation. On the load run, hold full load D.C. amperes and volts constant with minimum input field current. The load should be kept on at least one hour after all temperatures are constant. At the end of the run, temperatures must be taken on all parts of the machine
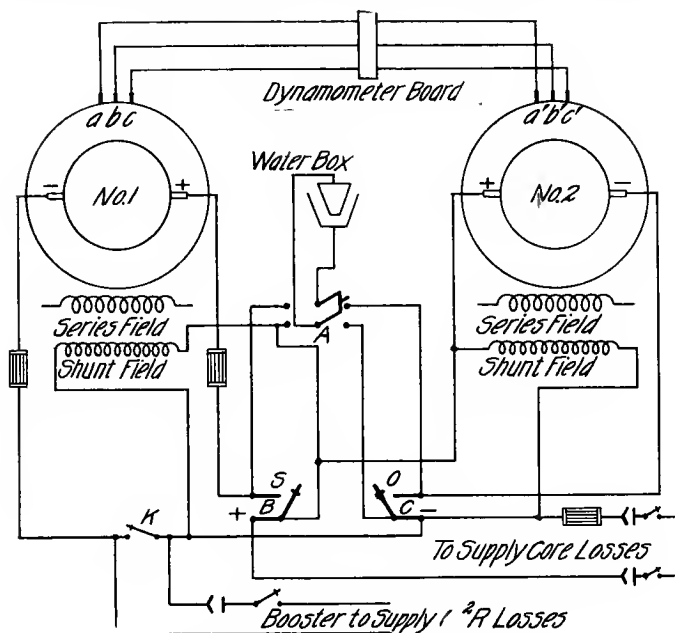

Fig. 64
CONNECTIONS FOR PUMPING BACK ROTARY CONVERTERS
WITHOUT THE USE OF A REGULATOR

and the resistance measured on the armature (A.C. end) and field. If the rotary is six-phase the armature resistance is measured between rings 1–4, 2–5, 3–6, counting outwards from the armature.

If an overload run is required, take a few points on the overload phase characteristic to determine the field current required for minimum input, then hold this current and the D.C. volts and amperes constant, as on the normal load run.

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After the heat runs, the tests should be finished by taking a phase rotation, hot drop on spools, D.C. running light at normal voltage, and D.C. starting tests. A.C. starting tests are only taken when especially requested.

D.C. Circulating Current

Fig. 64 shows the connections for two three-phase converters wired for a pump back heat run, without a potential regulator to control the load. The core losses and I^2R losses are supplied from the D.C. end. The diagram shows, also, the standard starting panel which should always be used when two converters are tested together.

To start the rotaries, choosing No. 1 for instance, close the shunt field switch and switch K, which short circuits the armature of the loss supply. Note that the shunt fields are wired across the core loss supply, which is wired to busses B and C of the starting panel, and that the series fields are left open. Throw switch A to the left and slowly reduce the resistance of the water rheostat till it is practically short circuited, when switch S may be closed. The blade of the water rheostat is drawn out of the water and the switch A thrown to the right. Machine No. 2 is then started in a similar manner.

The strength of the field of each machine is then decreased until they both run at normal speed. Now connect a number of incandescent lamps in series, of which the rated voltage is equal to the sum of the machine voltage across rings AA; *viz.*, across switches located on the dynamometer board. Two sets of lamps should be provided, one being connected across one of the switches while the other steps across each of the other switches in turn. Should one set show a rise and fall in voltage directly opposite to that of the other, the two phases are reversed, and must be corrected. When all phases show a simultaneous rise and fall, the machines may be phased together, bringing their speeds to the same value by changing the field on one of them. When the rise and fall of voltage shown by the lamps decreases to a period of 5 seconds or longer, close all the switches simultaneously, when the lamps are dark.

During the period of starting and phasing the machines together, the boosters should be short circuited, with open fields. When the machines are synchronized the short circuits are removed. Apply a weak field on the booster and watch the line meter on No. 1. The reading of this meter should reverse from that given on motor load if No. 1 is taking load as a rotary. By reversing the booster field either machine can be made to run as a rotary.

After balancing the current in each phase, full load phase characteristics may be taken, by holding the speed constant by means of the field of the inverted machine, and the load constant with the booster, varying the shunt field of the rotary throughout its range and reading current input. Full load voltage ratio should next be taken, after which the heat runs may be made.

A line shunt must be used in each side of the D.C. circuits. The currents flowing through them must have equal values, otherwise one line has more resistance than the other, the unbalanced current returning through the A.C. ends of the machines. The currents in these lines can be balanced by decreasing the resistance of copper to the low reading line. The D.C. currents should be balanced before attempting to balance those in the A.C. side.

In running a pump back test there will be a slight difference in the D.C. voltages equal to the IR drop of the machine. The field of the inverted machine will be less than that required for minimum input. The machine will carry the additional current necessary for supplying the core losses.
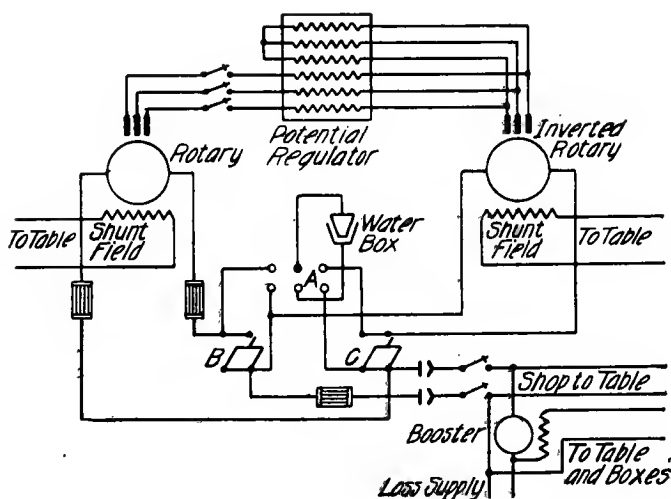
Fig. 65

CONNECTIONS FOR PUMPING BACK ROTARY CONVERTERS
WITH REGULATOR

This method of supplying the I^2R losses with a booster requires such a large low voltage booster that it is not often used except for small rotaries.

With a Booster in the A.C. Side

A second method of pumping back rotaries for full load heat runs, is to use an IR voltage regulator, in the A.C. side

of the machines as shown in Figs. 65 and 66. The regulator is connected with its secondaries in series with the A.C. lines and its primaries excited from the inverted machine. It is always preferable to connect the regulator between the inverted rotary and the dynamometer board. The regulator takes the place of the booster used in the previous method, and is very satisfactory for supplying the I^2R losses.

Starting the machines, checking the phase rotation, phasing in, and the other matters already described are repeated with this method. Always see that the regulator is set at the no boost point before phasing in, otherwise load will be thrown on, when the switches are closed.

Load is increased by turning the core of the regulator in the direction of boost, at the same time watching the ammeter of machine No. 1. If the reading reverses from motor load, then No. 1 is running as a rotary. If No. 1 does not reverse,
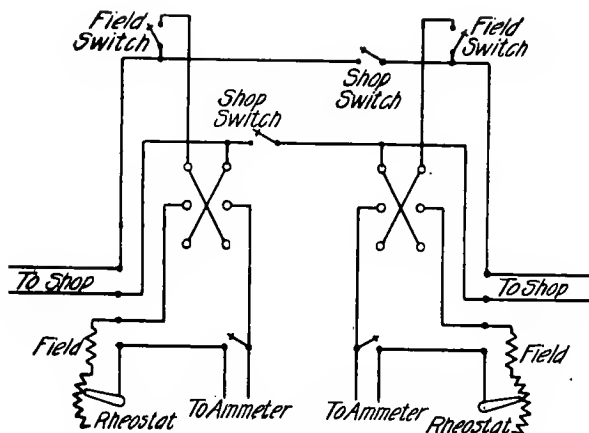
Fig. 66
TABLE CONNECTIONS FOR ROTARY CONVERTER PUMP BACK

turn the regulator in the opposite direction. This shows that the regulator is wrongly connected in reference to its markings. There is no necessity, however, to change connections.

Using A.C. Loss Supply

If instead of supplying the losses from a D.C. source of power, we connect an alternator across the A.C. lines, between the inverted rotary and the IR regulator, in the preceding

method, the losses can be supplied at the A.C. end. When the alternator is large enough to start the rotaries, the wiring on the D.C. end is greatly simplified. The starting panel is omitted, and the shunt fields are connected according to the print of connections for the machine. Load is obtained by means of the regulator as before and the test carried out as already described.

If the alternator is too small to start the machines, the latter may be started from the D.C. side as before, and phased together. The alternator is then synchronized on the pair. If only one machine can be started by the alternator, bring it up to speed, then open all its circuits, and let it run by its own momentum, and quickly start the second machine. Take off the excitation from the alternator field, and then close the switches on the first machine. Excite the alternator field, and bring both machines up to speed, together. After the machines are once started they can be brought up to speed without excessive current being required.

Short Commercial Test

The short commercial test consists of the following stationary and no load running tests:

Cold drop on spools.
Polarity tests.
Cold resistance of armature from A.C. end.
Checking spacing of equalizer and collector ring taps.
Air gap measurement.
Brush spacing and fit.
No load voltage ratio.
Volts between collector rings.
Running inve. ed, at 110 per cent. A.C. volts for one hour.
D.C. running light readings.
End play check.
Phase rotation.
Speed limiting device adjustment.
High potential test.

Long Commercial Test

This consists of the following tests:
Cold voltage drop on spools.
Polarity tests.
Cold resistance of the armature from the A.C. end.
Check spacing of equalizer and collector ring taps.
Air gap measurement.
Brush spacing and fit.
No load voltage ratio.
Volts between collector rings.

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Run inverted at 110 per cent. A.C. volts till temperatures are constant.

Measure hot resistance of the armature from the A.C. end and take temperatures.

D.C. running light readings.

D.C. starting test.

Phase rotation.

End play check.

Speed limiting device adjustment.

High potential test.

ALTERNATING CURRENT GENERATORS

The preliminary tests taken on A.C. generators consist of drop on spools, resistance measurement, air gap, fitting of collector brushes, phase rotation and the balancing of the voltages across the different phases.

Special Observations

On self-contained, belted generators, especially those having direct connected exciters, a reading should be taken with the alternator open circuited with full excitation voltage on the field.

On certain standard engine-driven generators only ballistic tests need be made.

During the tests on turbine-driven generators the machine should be carefully watched for any mechanical field unbalancing.

Besides the preliminary tests mentioned above, further tests should be taken as follows when requested:

Complete Tests consisting of special tests and temperature tests.

Special tests include saturation, synchronous impedance, open and short circuited core losses and wave form.

General tests include saturation and synchronous impedance. From these tests the regulation of the machine is calculated as follows:

Let V = normal voltage line, I = Amperes line, R = Hot resistance between lines.

$$I \text{ for three-phase machines} = \frac{\text{Kw.}}{\text{voltage}_1\sqrt{3}}$$

$$I \text{ for two-phase machines} = \frac{\text{Kw.}}{2 \text{ voltage}}$$

Voltage drop in armature, for three-phase machines $I_1R_1 = \frac{\sqrt{3}}{2} IR$

for two-phase machines $I_1R_1 = IR$

Let a_1 = amperes field on Saturation Curve corresponding to $V + I_1R_1$ and a_2 = amperes field on the Synchronous Impedance Curve corresponding to I.

The amperes field required to produce normal rated voltage with full load on the generator will be $a_3 = \sqrt{a^2_1 + a^2_2}$

Let the voltage on the saturation curve corresponding to $a_3 = V_1$

Then the per cent. regulation $= \dfrac{V_1 - V}{V}$

If it is desired to calculate the regulation of the machine at any power factor, then I becomes $\dfrac{I}{\% P.F.}$ and

$a_3 = \sqrt{a^2_1 + a^2_2 + 2 \ a_1 \ a_2 \sin \ \theta}$

when θ is the angle of which the per cent. power factor is the cosine.

Input Output Efficiency Test is made by the input output method.

Standard Efficiency Test is made by the method of losses.

The method used in the calculation of a standard efficiency is as follows:

Let V_L = volts line W_b = output = $\sqrt{3}\ V_L\ I_L$ for three-phase and $2\ V_L\ I_L$ for two-phase

I_L = amperes line R_1 = hot res. of armature between lines

I_1 = amperes field R_2 = hot res. of field

W_1 = open circuit core loss corresponding to $V_L + IR$ on the core loss curve

W_2 = short circuit core loss corresponding to I_L on the short circuit loss curve

W_3 = friction and windage obtained from core loss test

I_1 is calculated for each load, as when calculating for regulation

IR is the drop in the armature = $\sqrt{\frac{3}{2}}\ I_L\ R_1$ for three-phase machines and $I_L\ R_1$ for two-phase

$\Sigma W = W_1 + \frac{1}{3}\ W_2 + W_3 + \frac{3}{2}\ I_L^2 R_1 + I_1^2\ R_2$ for three-phase machines

$\qquad = W_1 + \frac{1}{3}\ W_2 + W_3 + 2\ I_L^2 R_1 + I_1^2 R_2$ for two-phase machines

Watts input = $W_a = W_b + \Sigma W$

Efficiency = $\dfrac{W_b}{W_a}$

W_3 need not be considered if the machine is furnished without base, shaft or bearings.

The above method of calculation is used when the machine is to operate at unity power factor.

If it is desired to calculate the efficiency at any power factor the following calculations must be made.

$I_L = \dfrac{\text{Kw.}}{V_L \times \sqrt{3} \times \% \ \text{P.F.}}$ and $W_b = \sqrt{3} \times V_L \times I_L \times \%$ P.F. for three-phase machines

$I_L = \dfrac{\text{Kw.}}{V_L \times 2 \times \% \ \text{P.F.}}$ and $W_b = 2 V_L \times I_L \times \%$ P.F. for two-phase machines

I_1 should be calculated for various power factors as given under regulation.

The change in the line current will affect:

I_1, W_1, W_2, and the $I^2 R$ of the armature. See Fig. 67 and Calculation Sheet 12.

Non-inductive Normal Load Heat Run consists of running the machine under normal load at unity P.F. until constant temperatures are reached. These final temperatures are then recorded and readings taken of regulation with unity power factor.

Non-inductive Overload Heat Runs consist in bringing the machine to normal load temperatures, applying the overload at unity P.F. for the specified time and recording the overload temperatures. Readings for regulation at unity P.F. should be taken.

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Normal Load and Overload Power Factor Heat Runs are made in the same way as that for normal and overload non-
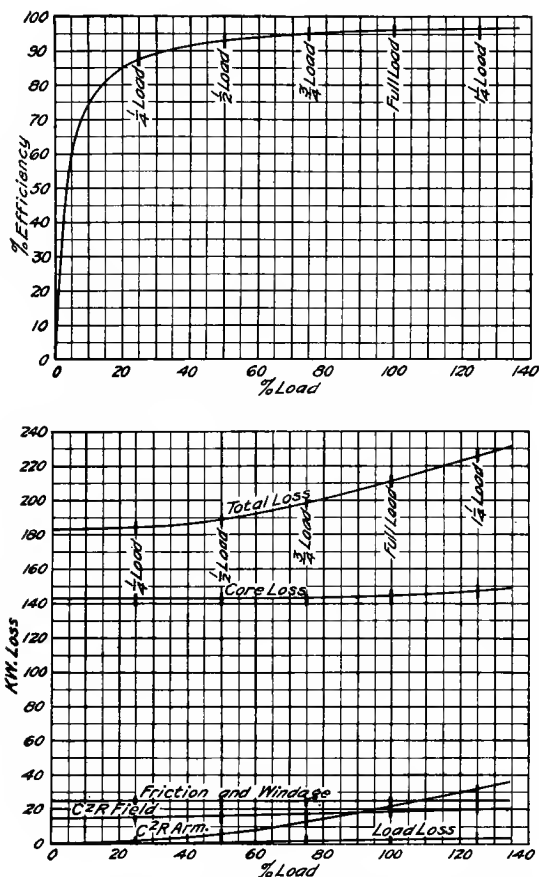

Fig. 67

EFFICIENCY AND LOSSES ON A 5000 KW., 11,000 VOLT, 257 R.P.M.
60 CYCLE, 3-PHASE A.C. GENERATOR

inductive runs except that the machine is operated at a specified power factor. Wattmeters should be used with the voltmeter and ammeters to determine the P.F.

The Short Commercial Test consists in running the machine open circuited at 110 per cent. normal voltage, to insure that it is an electrical duplicate of previous machines of the same type and free from manufacturing defects.

The Long Commercial Test consists of taking "General Tests" together with two heat runs, one open circuited at 110 per cent. voltage and one short circuited at 125 per cent. current. These percentages are for machines having "A" guarantees. For machines having "B" guarantees 115 per cent. voltage and 150 per cent. current should be used. Each of these runs should be continued until the temperatures are constant. The machines are then shut down and the final temperatures recorded.

Stationary Tests consist of stationary impedance, phase rotation, resistance and high potential.

On some of the larger machines and particularly on turbo-generators, an open delta circulating heat test is made until temperatures are constant. This test has already been described on Page 121.

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SYNCHRONOUS MOTORS

The preliminary tests taken on synchronous motors consist of drop on spools, air gap, resistance measurement, balancing of phase voltages, phase rotation, and running free minimum input.

Complete tests consist of special tests, normal and overload heat runs.

Special tests consist of starting tests, open and short circuited core loss, saturation, synchronous impedance, no load and full load phase characteristics and wave form. The method of taking phase characteristics has previously been described.

Starting tests should be made both with and without a compensator, if the motor is of a new type and rating, and must be started with a compensator when installed. If the motor does not form part of a motor-generator set, it should be belted to its load generator in order to have some load at starting.
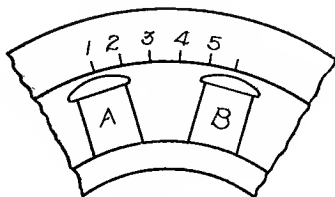
Fig. 68

The motor should first be tested for starting, without the compensator. The center line of one pole is placed in line with the center line of the frame. At the head end of the motor a length of 180 electrical degrees is marked off in a clockwise direction from this line. The total length of the scale used should be two-thirds of the distance between the center lines of adjacent poles for three-phase machines, one-half for two-phase machines and one-third for six-phase machines. The scale should be divided into four equal parts, each division line being numbered. On each one of these scale divisions, the center line of the marked pole should be placed and the motor started. Thus five tests are made to insure that the motor will not stick in any position. See Fig. 68.

With the pole A moved to position No. 1 and the machine at rest, sufficient current should be sent through the armature to give a reasonable reading of amperes and volts on the various phases and induced volts on the field. The induced volts field should be read by a potential transformer and A.C. voltmeter. The readings with the machine at rest are taken to determine which phase gives the maximum readings of current and voltage, so that the latter can be read at the moment of starting.

With the switches adjusted to give the maximum reading, the armature current is increased until the motor starts. Volts armature, amperes armature and induced volts field are simultaneously read. The starting voltage is now held constant until the motor comes to synchronism, the time required to reach this point being recorded. The machine attains synchronism when the induced volts on the field fall to zero. Then machine is shut down and the tests are repeated from each of the other positions.

If a motor shows a tendency to remain at half speed the A.C. voltage should be increased until the motor breaks from half speed and comes up to synchronism. The voltage required to break the motor from half speed is then held and recorded until full speed is reached.

All starting tests should be recorded on a Special Record Sheet provided for the purpose and a sketch should be made showing the starting positions. If the motor sticks at half speed a record should be made.

If the test is required with a compensator the motor should be set with its field in the position where greatest starting current is taken and allowed to rest in that position for at least six hours until the oil is well pressed out of the bearings. This is done in order to obtain the worst starting conditions likely to occur in normal operation. Connections are then made to the lowest tap of the compensator and with normal voltage held on the line the starting switch of the compensator is closed. If the motor fails to start, the voltage must at once be switched off and connections made with the next higher taps on the compensator, and so on until the motor starts. Readings should be taken at rest on each of the taps of the compensator, in the starting position, to determine the voltage ratio of the taps of the compensator. All these tests should be made with the field circuit of the motor open. During the tests with compensator, enough time should be taken between the trials to allow the compensator to cool, as it is designed for intermittent service only. See Calculation Sheet 14.

General tests consist of saturation and synchronous impedance.

Input output efficiency test is made by the input output method.

Standard efficiency tests are made by the method of losses. In calculating efficiency, the same nomenclature is used as with A.C. generators. I_1 is either taken from the phase characteristics or is calculated.

Watts input $W_a = V_L I_L + I_1^2 R_2$
Watts output $= W_b = W_a - \Sigma W$
Efficiency $= \dfrac{W_b}{W_a}$
$W =$ open circuit core loss corresponding to $V_L - IR$ on the core loss curve
Horse-power output $= \dfrac{W_b}{746}$

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Calculation Sheet 13 and Fig. 69.

Non-inductive load heat run consists of the following: Running the machine under load at unity power factor, until it has reached constant temperature, and recording tempera-
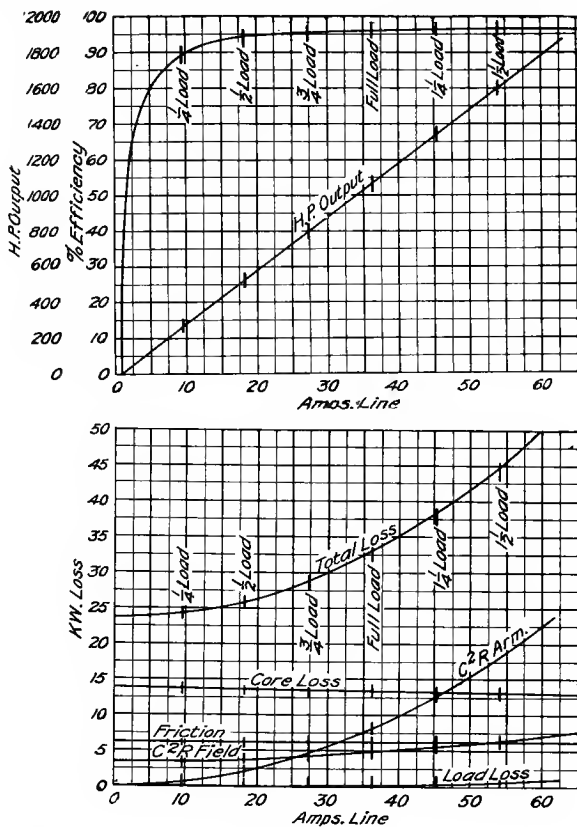

Fig. 69

EFFICIENCY AND LOSSES ON A 1070 H.P., 13,200 VOLT, 500 R.P.M. 25 CYCLE, 3-PHASE SYNCHRONOUS MOTOR

tures. Taking readings of regulation at normal and no load and full load phase characteristics.

Non-inductive overload heat run consists in bringing the machine to normal load temperature, applying the overload

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for the specified time, recording temperatures and taking readings of regulation at unity power factor.

Normal load power factor heat run is the same as normal load non-inductive, except that the machine is operated at a specified power factor. Wattmeters should be used as described with A.C. generators.

Overload power factor heat run is the same as overload non-inductive, except that the power factor is less than unity.

In making the short commercial and long commercial tests, the machine should be run as a generator under conditions similar to those used under A.C. generators. The same applies to the open delta circulating heat test.

INDUCTION MOTORS

The test usually made upon Induction Motors for checking guarantees, and determining characteristics for engineering information are given under the following headings. Wherever these tests differ from those employed for other alternating current motors they are described in more detail.

The preliminary tests made on induction motors are air gap, bearing play, starting, slip, resistance measurement, running light, excitation, static impedance and end play.

Special measuring scales are used in taking induction motor air gap and considerable care should be taken in this measurement both with the rotor in one position and in different positions.

Bearing play is taken by measuring the gap at the top, bottom and on each side. With the motor in the same relative position to the stator, *i.e.*, without turning the rotor, the motor is turned over in all four positions of the quadrant and the same measurements of air gap taken. Any defects in the bearings which may affect the air gap of the machine are thus disclosed.

A starting test on Form K motors is made by switching the machine on the line at a low voltage and then increasing the voltage until the motor starts, the current and voltage at this point being recorded. This test is occasionally made with a compensator. The starting current should not exceed 200 per cent. normal current.

Full line voltage should be impressed on Form L motors with all the internal resistance in the motor circuit, and the starting current recorded. This current should not exceed normal current.

Form M motors are started at full line voltage with all the external resistance in the rotor circuit, the starting current being recorded. This current should not exceed normal value. Sometimes the collector rings on Form M motors are short circuited and the starting test made at reduced voltage, as in the case of Form K motors.

Slip is usually measured at full load and running light by means of the Slip Indicator, the construction and use of which has been previously explained. Constant speed must be held on the driving alternator and constant load and voltage on the motor during this test.

To take slip by the lamp method an arc lamp is connected in the circuit from which the motor is running. On the end of the shaft of the motor a disk is located having as many white and black sectors as there are poles in the motor. See in Fig. 70, which is used for a six-pole motor.

As the lamp is running from an alternating current source, the current wave passes through zero twice in each complete cycle. At the zero instant, the light given out by the lamp is a minimum.

Consider a six-pole 60 cycle motor running at 1200 r.p.m. Let the motor run at synchronous speed; that is to say, at 20 revolutions per second. Then $20 \times 6 = 120$ black sectors pass a stationary point on the circumference of the disk in one second. As the frequency is 60, the number of maximum illuminations will be 120. At each maximum illumination, therefore, the black strips will always occupy the same positions. The slip, which always occurs in an induction motor, will cause a black strip to lay a small angle behind that seen by the previous illumination. These successive differences in position appear as a sector rotating backwards which can be followed by the eye. The slip, *i.e.*, the difference between the actual speed and the synchronous speed of the motor per minute, can thus be counted.

The resistance of the stator should be measured cold and hot.
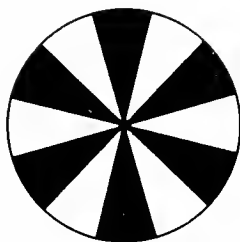
Fig. 70
SLIP DISK

Running light is taken by applying normal voltage to the stator, and reading and recording the amperes input to the motor.

Static impedance is taken by blocking the rotor and applying such a voltage to the stator as will give about full load current, then reading and recording the current in each leg, together with the voltage between each of the legs. If the motor is of the Form L type, impedance is taken with the resistance all in and all out, always holding the same voltage across the stator. This practice has been found to give the best results.

End play should be tested both with and without voltage on the stator.

On all motors particular care should be taken to see that the rotor is in perfect balance.

When cutting out the internal resistance, the starting switch of Form L motors should be watched closely for sparking or any other defects. The brushes must make good contact on

the resistances in all positions. The switch must not work too easily, otherwise the resistance may be cut out too rapidly.

The brushes on Form M motors must fit the collector rings perfectly. A successful test on this type of motor depends considerably on this matter.

The voltage ratio should be taken on Form M motors by impressing normal voltage on the stator and measuring the voltage between the rings of the rotor on open circuit. Volts and amperes stator, and volts between rotor rings should be read and recorded.

Two speed motors can be obtained by changing the connections on the stator by means of a switch and connection board. These changes alter the number of effective poles, thus changing the speed. The rotor must have the correct number and ratio of slots in the stator and rotor, otherwise dead points may occur at certain starting positions or the motor may operate at subsynchronous speeds. These machines are usually run at the lower speed during test.

COMPLETE TESTS consist of special tests, normal and overload heat runs.

SPECIAL TESTS consist of making an excitation and impedance curve using wattmeters, and a stationary torque curve on Form K motors.

Excitation

Excitation and impedance are important tests. The following precautions must be observed in all cases. The calculation of the characteristic curves of Induction Motors depend entirely on test results, and great care must therefore be taken to obtain accurate measurements.

The motor should be located so that all the conditions affecting its operation during test remain unchanged throughout the run. A solid foundation is necessary to prevent vibration at full speed. See that the bearings are supplied with oil. The table must not be near to any source of stray field. The driving alternator should be at least $\frac{3}{4}$ the kw. capacity of the motor. The transformers and other apparatus must be connected so that the alternator is working under normal conditions, since satisfactory wattmeter readings cannot be obtained if the alternator is run too low on the saturation curve. Transformers, when used, must be well balanced and not forced beyond their voltage range, otherwise unsatisfactory results may be obtained.

The table must be adapted for wattmeters by providing a special wattmeter switch connected on two of the three phases as shown in Fig. 71. A and B are the terminals for the current leads to the wattmeters—X and Z being the short circuiting switches. Calling the phases 1–2–3, phase 1 is on the current coil of wattmeter R connected at A. The pressure coil is connected across 1 and 2. Likewise with the other meter S. Its current coil is on phase 3 at B and its pressure coil between 2 and 3. If the voltage is too high for direct use on wattmeters, multipliers (non-inductive coils of known resistance) or potential

transformers must be connected between the meter and the volt lines at the table.

On motors of less than 20 h.p. the lines to the primaries of the potential transformers must be attached to the generator side of the lines coming to the top of the dynamometer board. If on the motor side on the top of the board, or on the motor terminal block, the excitation current of the potential transformer passes through the wattmeters. Although this current is small, with a small motor it may be an appreciable percentage of the excitation current of the motor. Hence an error is caused and an abrupt break made in the excitation curves every time the ratio of the potential transformer is changed. On large
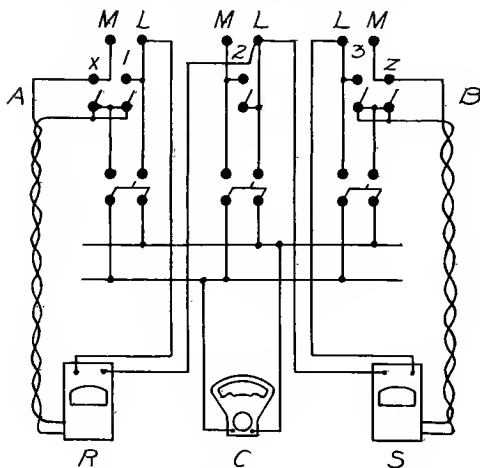
Fig. 71
WATTMETER CONNECTIONS FOR EXCITATION

motors the excitation current of the potential transformer is so small in comparison with the motor current that the incidental errors are negligible. The above does not apply to multipliers because they are non-inductive.

On large motors the volt leads should always be attached at the terminal block, to eliminate the line drop in switches and leads from the table to the motor. The current leads to the wattmeters should be twisted together throughout their length and come direct from the terminal to the meter without loops or sharp turns. All connections must be kept tight and clean.

The air gap should be taken before a test is started. On voltages above 500 volts all instruments must be discharged to

eliminate static charge. A small fuse should be provided connecting the current terminal to the nearest volt terminal of the wattmeter. Do not ground the secondaries of the transformer.

As soon as machine is wired and ready to start, the switches on the dynamometer board should be closed. (Always see that the wattmeter switches are closed whenever a change in the field current is made.) The exciter field switch is then closed and the voltage brought up slowly until the motor starts and reaches normal speed. The machine should then be inspected to see that it is operating normally. The amperes and volts in the different phases should then be read and any unbalancing corrected or its cause discovered.

The end play of the motor should be tested next, since the rotor must always run centrally in the frame. A slight pressure against one side will change the friction watts and give an incorrect value to the core loss. Small motors should be run about one hour and a half and large ones two hours and a half or more, to obtain constant friction before starting tests. If the wattmeter needle goes off the scale in a negative direction when connected in circuit the current leads on the current terminals should be interchanged. On a two-phase circuit, with a machine under load, both wattmeters should read positive.

For running light readings on a three-phase machine the sign of the meter must be determined, one being negative on the upper part of the curve. With both meters reading in a positive direction open one of the phases containing the current coil of the wattmeter and observe the other meter. If the needle drops off the scale below zero the meter reads negatively. If the needle drops to some value above zero the reading is positive. This process must be repeated for determining the readings of the other wattmeter.

The alternator speed must be held constant during the test. About 130 per cent. normal volts must be used for the first reading. Volts, amperes, watts and speed of generator and motor should be read and recorded. The volts should then be decreased in steps so as to obtain about 20–25 points on the curve down to 10 or 15 per cent. of normal volts. Here the conditions are no longer stable. The meter with a negative sign will read less than the other, and its readings will fall off more rapidly than the others, becoming less and less until zero is reached and its sign changes. When it becomes positive the current leads must be interchanged.

To check the results: After the volts have been reduced from the starting point of curve to normal, three single-phase readings, one above, one below and one at normal voltage, should be taken on the two legs using wattmeters. Check readings should also be taken with a different voltmeter and ammeter.

The single-phase excitation amperes are theoretically 1.73 times the three-phase and twice the two-phase. That is, the

k.v.a. has equal values for the motor, whether single-phase or polyphase. Practically, the single-phase amperes are from 1.6 to 1.7 times the three-phase, instead of 1.73 times. The same ratio holds on quarter-phase.

The watts excitation are the same so far as core loss is concerned for polyphase or single-phase. The increase in watts single-phase over the watts polyphase is equal to the polyphase I^2R. For instance, if the three-phase excitation requires 1000 watts and the I^2R three-phase is 100 watts, the single-phase excitation will be 1100 watts.

Before shutting down, a curve should be plotted with volts as abscissæ and the algebraic sum of the watts as ordinates.

Wattmeter work is somewhat uncertain, and accurate results can only be obtained under good conditions. An endless belt on the driving alternator is necessary, a laced belt making the wattmeter needle swing with a steady beat corresponding to the lacing striking the generator pulley. Any belts running near the table must have their static charges drawn off by a grounded wire. The cases of all transformers should be connected together and grounded. Wattmeters must be carefully handled on high voltages. As all three phases of the alternator are connected on the table, wattmeter work at high voltages involves danger, since contact between two of the instruments short circuits two of the phases.

The two important points on an excitation curve are the watts at normal voltage and friction watts. These points determine the per cent. core loss of the motor. Several readings, only a few volts apart, should be taken on each side of normal voltage. The volts and amperes in the different phases at two or three other points in the curve should be carefully read and recorded as a check on the balance of the motor. As the lowest point of the curve or friction reading is approached, many readings should be taken. This portion is the most difficult part of the curve to locate, especially in the case of large motors. In many cases "hunting" begins at a low voltage. A reading taken when the motor is accelerating is of greater value than the steady reading.

Hunting usually makes the meter needle swing with a slow beat. The range of the beat varies with the size of motor and degree of hunting. Bad cases of hunting are not numerous and reliable readings can generally be secured between beats. To test successfully, the speed of the driving generator must be kept constant and no reading should be taken until the speed is properly adjusted. The tachometer used must be carefully checked.

The excitation tests on all forms of Induction Motors are the same.

The Form M Induction Motor is provided with collector rings for the external resistance. These must be short circuited at the brush-holder terminal and the brushes must be carefully sandpapered until they accurately fit the rings.

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Calculation of Excitation Test on Induction Motors

All readings must be corrected for the instrument constants and ratios used. Special care should be taken to use the proper signs for the wattmeter readings.

Calculation Sheet No. 15 shows the form used in calculating an excitation test, and Fig. 72 shows the method of plotting an excitation test.
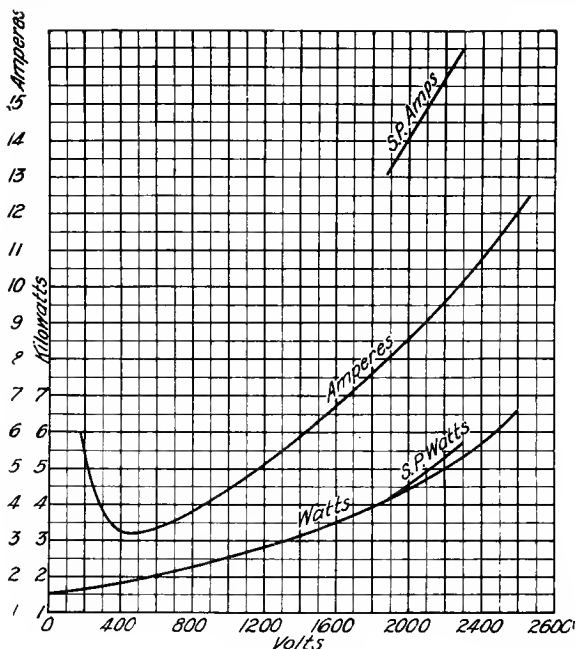

Fig. 72
EXCITATION CURVE ON A 100 H.P., 2080 VOLT, 1200 R.P.M., 60 CYCLE, 3-PHASE INDUCTION MOTOR

The friction and windage watts are obtained from the excitation curve by producing the watt curve to zero volts.

Impedance

The Form K motor has a symmetrical bar winding in the rotor, therefore the impedance is the same for any position of the stator relative to the rotor.

In Forms L, M, and P, a position curve is first taken. Two-thirds of the distance between two consecutive poles on a three-phase motor and one-half that distance on a quarter-phase

motor are marked off on the bearing bracket. This space is divided into about eight parts. A pointer should then be attached to the motor shaft or pulley so that its outer end will pass over the division marks. The pointer is set on mark No. 1 and the rotor blocked so that it cannot move from that position. The switches are then closed and the impressed voltage increased gradually until about normal amperes are obtained. Volts and amperes should be read and recorded on all three phases to
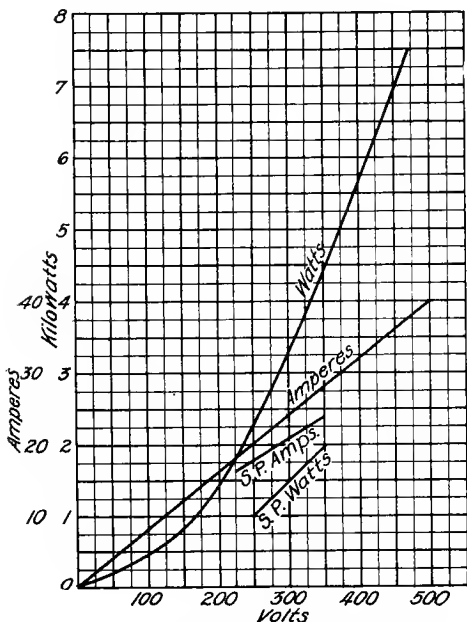
Fig. 73

IMPEDANCE CURVE ON A 100 H.P., 2080 VOLT, 1200 R.P.M., 60 CYCLE, 3-PHASE INDUCTION MOTOR

be sure that no unbalancing occurs. Holding the same volts as in position No. 1 the pointer is moved to mark 2, and the amperes read. This is repeated on each of the succeeding marks. A curve is plotted giving amperes and pointer position. The motor is then blocked in the position which gives an average value of the current. Form K induction motors are blocked in any position.

The amperes are then increased until 150 per cent. normal amperes are obtained, reading and recording the amperes,

volts and watts. The sign of the wattmeter must be determined in the same way as at the beginning of the excitation test. About six or eight readings should be taken between zero and 150 per cent. normal current. The current should not be held on the motor longer than necessary to secure a reading; after each reading the exciter field should be opened, until ready for the next reading, otherwise the motor will get too hot. As soon as the readings are taken curves should be plotted with volts as abscissæ and amperes and the algebraic sum of the watts as ordinates. The ampere curve should be a straight line, though sometimes the top portion curves upward very slightly.

Single-phase check readings should be taken, one above, one below and one at normal amperes on the two phases containing wattmeters.

Fig. 74
MEASUREMENT OF TORQUE BY MEANS OF SPRING BALANCE

The single-phase impedance amperes should be 86.5 per cent. of the three-phase (line values). The impedance watts single-phase will be approximately half of the three-phase. In a quarter-phase motor single-phase impedance is that of one of the two phases.

On Form M motors, when taking impedance, the collector rings should be short circuited either by metal brushes or by metal strips, as the contact resistance varies with carbon brushes. The ratios between the primary and secondary voltage, should be taken with the secondary open circuited.

Calculation of Impedance Test on Induction Motors

Calculation Sheet No. 16 shows the form used in calculating an impedance test, and Fig. 73 shows the method of plotting an impedance test.

Torque

Two methods are used in taking torque on induction motors, one with a spring balance and the other with a special torque indicator.

In the first method a wooden brake lever is clamped around the pulley as shown in Fig. 74. The size and length of lever used depends on the size of the motor, the length being chosen to give a maximum reading at one-half or two-thirds the full capacity of the spring balance used. Let the point of attachment to the lever be at X. Then the length of the lever arm = XY On the frame of the motor a mark should be made at M, and to the brake attach a pointer P. The lever arm is then raised until the distance $XT = YS$ and the pointer set so that it is on mark M with the lever in this position. If the weight of the lever alone is not sufficient to overcome the friction of the bearings and turn the rotor around till the end of the lever touches the floor, attach a weight at W. Now when the spring balance H is pulled upwards until the pointer P is on mark M, XY is parallel to TS, and the pull X makes an angle of 90° with the center of the shaft, the position in which all readings must be taken. Open all switches on the dynamometer board to eliminate the residual magnetism of the alternator, raise the lever arm by pulling vertically on the spring balance till the pointer passes the mark M, and at the instant of passing take a reading of the spring balance. Call this reading $W + F$. Let the lever be raised until the pointer is some distance beyond M. Then lower the spring balance and let gravity pull the lever toward the floor, reading the balance when the pointer passes the mark. Call this reading $W - F$. To get good readings the lever arm should be moved rather slowly, but steadily, and as nearly constant speed as possible, a reading of the balance being taken every time the pointer passes the mark. Three or four readings should be taken as described above as a check.

Close the line switches and increase the amperes up to twice normal and take readings as above. Also read volts and amperes. Call $W + F + T$ the reading obtained as the pointer passes the mark, as the lever goes up, and that obtained as it comes down $W - F + T$, T representing torque.

Readings should be recorded as below.

Volts	Amps.	$W + F$	$W - F$	$W + F + T$	$W - F + T$	T
150	40	9 lbs.	5 lbs.	19 lbs.	15 lbs.	10 lbs.

Assume the above readings taken on a 440 volt motor. To find the torque:

$2W = 14. \therefore w = 7$ lbs.
$2(W + T) = 34$ lbs.
$\therefore T = 10$ lbs.

Torque at 1 ft. radius $T \times L$.
Where $L =$ length of lever arm.
Torque at 1 ft. radius at normal volts

$$= \frac{(\text{normal volts})^2}{(\text{ volts read })} \times T \times L$$

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On squirrel cage or wound rotors a value of current should be used which will make $W + F + T$ at least twice $W + F$. The maximum and minimum values of $W + F + T$ and of $W - F + T$ should also be taken.

All wound rotors will show a torque variation, and most squirrel cage rotors will have a slight variation, depending on the rotor position.

As a check on the torque readings the lever should be loosened on the pulley and the pulley rolled forward until the mark on its rim at N is in line with a second mark on the lever arm, thus changing the relative positions of the rotor and stator Further readings should be taken. Repeat on four or five different points. The torque should be the same on all points in Form K motor.

The special considerations to be observed in taking torque are constant and correct generator speed throughout the test. The volts read, when amperes are 200 per cent. normal on the first point, should be held constant on all other points, since the torque varies as the square of the volts. The torque also increases as the resistance of the secondary increases due to heating. On large machines the secondary sometimes becomes quite hot, so that the temperature of the end rings and bars of the winding should be taken and recorded.

Starting Resistance

The Form L motor has a starting resistance in the rotor which is controlled by means of a rod sliding within the shaft in the smaller sizes, and a lever and ratchet combination on the larger machines. The resistance of the different starting steps must be measured.

The rod should be pulled out to the limit by means of the knob handle, thus putting all the resistance in circuit. The rod is then divided into five equal parts. From the impedance test find what voltage will give about 125 per cent. normal amperes, when the rod is in the running position, *i.e.*, the resistance all cut out. With the rod in the first position read the volts and amperes. Continue this till readings have been taken on each of five different steps marked on the rod. The same procedure holds good on the larger machines where the resistance is cut out step by step. These readings with the resistance in circuit must be taken as quickly as possible, otherwise the resistance becomes unduly heated and may be injured.

Calculation Sheet No. 17 shows the form used in calculating stationary torque on Induction Motors.

The construction and operation of the stationary Torque Recorder have already been described. The following precautions must be taken in using the stationary Torque Recorder:

Before starting a torque test, see that the motor will turn in the right direction, otherwise the recorder may be destroyed or injury result to the tester.

The recorder should be placed vertically, as considerable friction will result if the pull is to one side. The cord used

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should have no tendency to twist when decreasing in length. In taking the cards the diagram need only cover one pole phase, to represent a complete torque cycle on the motor. Normal voltage should be held as closely as the heating of the motor or the grids in the case of a Form M machine, will allow. When this test is made with a controller, a card should be taken for each controller step. The grids should never be allowed to become too warm since the resistance changes rapidly with the temperature. If cards are taken on the various resistance steps with widely different temperatures on the grids, the results will not be consistent.

General tests consist in making excitation and impedance tests with wattmeters, single-phase, at points near normal voltage and current respectively.

Input Output efficiency and Power Factor tests can be made by either the "string brake" or "pumping back" methods. Neither of these methods are particularly accurate nor are
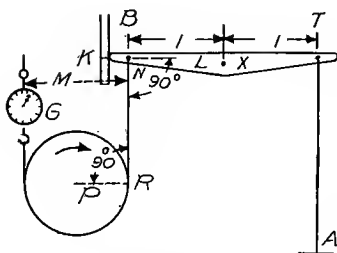
Fig. 75

DIAGRAM OF APPARATUS USED IN TAKING INPUT OUTPUT BY THE STRING BRAKE METHOD

they recommended. In certain cases, however, these tests are used on Induction Motors.

In Fig. 75 L is a lever or scale beam suspended at the point X. From T the small platform A is suspended, on which calibrated weights are placed. P is a *flat* faced pulley on the shaft of the motor running in the direction shown by the arrow, *i.e.*, toward the lever L. One end of a small rope is attached at B, which is wound one or more times around the pulley. The other end is made fast to a spring balance G. A strip bearing a mark is located at K so that when the point of the lever L comes opposite to the mark, the lever is in a horizontal position at an angle of 90 degrees to the force exerted by the pulley.

Since the stress along a rope is transmitted through its center, adjust the brake until the points M and N are a distance

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apart equal to the diameter of the pulley plus the diameter of the rope, one-half the diameter of the rope being added to each side of the pulley. This adjustment must be carefully made and care taken to see that nothing moves to throw the brake out of line or proper adjustment. When ready slip the rope off the pulley but leave it attached at B and G, then balance the lever until the pointer on the end comes to rest at the mark K. This balancing of L must be repeated each time the rope is changed.

The motor should be run light for at least one hour before the test proper is commenced, so that friction may become constant. Since speed is one of the important factors in the output of the motor it should be taken very carefully. The slip should be taken with the slip machine.

Running light readings should now be taken on the motor. The voltage impressed on the motor should be held constant as well as the impressed frequency. Attach a small weight to the spring balance to give enough tension on the spring for a reading on the balance of a quarter or half a pound. This "no load" scale reading must be recorded and subtracted from all subsequent readings taken.

Put a small weight on A and pull up on the spring balance G until the pointer on lever L reaches K. Then when the motor volts and speed of the generator are normal and all meters are steady, read and record volts, amperes, watts, weights on A, spring balance reading and speed given by the tachometer. In the case of an induction motor, a reading should also be taken with the slip machine. Add more weight to A and take another readings, continuing in this manner until the breakdown load of the motor is reached. For an induction motor the readings should be recorded in the following manner:

Volts	Amps.	+ Watts	− Watts	Weight on A	Tension on balance	Slip	Speed of Motor

A rope of small diameter gives better results than a larger one, even though it may require more time to make the tests on account of having to renew it more frequently. On motors up to 20 h.p. a $\frac{1}{4}$ in. oiled hemp rope is best and a $\frac{1}{2}$ in. rope can be used up to 50 h.p. The rope will last longer, usually, if doubled and two strands used in parallel. The rope turns around the pulley should all lie closely and evenly together on the face of the pulley. The tension read on the balance G will vary with the temperature of the rope and may differ widely with different loads.

The additional weight put on A each time should be such as to give from fifteen to twenty readings between no load and breakdown.

When the breakdown point has been reached and complete readings taken and recorded the diameter of the pulley should be carefully measured.

Weight on A – tension on balance – "no load" reading on balance = actual load in pounds = P, normal speed – slip = actual speed of motor. R = Radius of pulley in inches + $\frac{1}{2}$ diameter of rope. S = Speed in revolutions per minute.

$$\text{Power factor} = \frac{\text{Watts}}{\text{Volts and amps.}}$$

Then $\text{H.P.} = \dfrac{2\pi R}{P \times 12 \times S \times 33,000}$

$$\text{Efficiency} = \frac{\text{H.P. output} \times 746}{\text{Watts input}}$$

When making any special test, the tester should see that the tests check among themselves before handing them in.

Efficiency by the Pumping Back Method

Consider Fig 76, let M be the motor and L the load machine. This should have about an equal capacity and be belted to
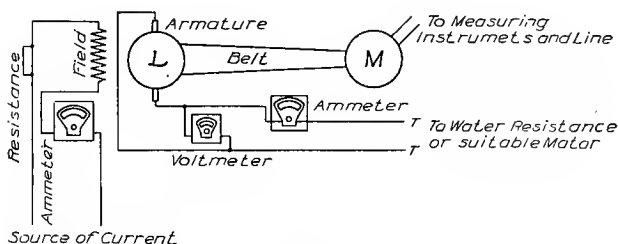
Fig. 76
CONNECTIONS FOR MEASURING INPUT OUTPUT BY PUMPING BACK

the motor M. It should be a direct current machine, and must be separately excited from a suitable source of energy.

To take the efficiency test, connect M so that the total input can be obtained. The necessary connections are not given, as they vary widely, depending on whether M is a direct current machine, or an alternating current machine of one, two or three phases, etc. Separately excite the field of L, connecting an ammeter and a variable resistance in circuit. Connect the armature of L to a water-box or a motor the load of which can be varied, placing an ammeter in the circuit and a voltmeter across the brush terminals. If the test involves a considerable range of speeds, run M over that range, and hold the field current of L constant, its value being such that the speeds or loads required for M can be obtained.

Having made the necessary connections, etc., keep the field current of L constant at its predetermined values. Vary the load on L by changing the water resistance or the load on the motor to which it is connected, to suit the testing conditions

required on M. The efficiency of M may be required for a series of speeds or of loads. Read the input and speed of M, and the volts and amperes of L, keeping the field of L constant and noting its value. The "counter torque" must now be obtained to complete the calculations.

To obtain this, disconnect M, connect L to a source of current which can be varied so as to give L different speeds, keeping L separately excited. If the "pumping back" method for loading L has been used, the connections will probably not require any change. Run L as a motor driving M, keeping the field current of L constant with the same value it had when L was used as a generator.

Vary the speed of L so that the speed of M can be varied slightly below its previous minimum speed to slightly above its maximum speed. Take a number of readings at varying speeds, reading volts and amperes input of L and speeds of L and M. If the electrical efficiency alone is desired (case A), sufficient readings have been taken. If the commercial efficiency is desired (Case B), take off the belt from L, and run it light as a motor. Vary its speed from slightly below to slightly above the speeds used before when running as a motor, and take a number of readings at different speeds, reading volts and amperes input and speed, separately exciting L, with the same current used in the two previous cases. The necessary readings are now complete for calculating the efficiency.

Case A

Let Wm be the total input of M.

Let Wl be the product of volts and amperes read for L.

Let Fm be $M's$ friction, windage, etc.

Let Fl be $L's$ friction, windage, etc.

Divide the belt friction equally between L and M including this in Fm and Fl.

Let R be the hot resistance of $L's$ armature, which must be measured.

Let I be the current in $L's$ armature.

Then electrical efficiency $= \dfrac{Wl + I^2R + CT}{Wm}$ where CT is the mechanical losses in L and M and the belt loss.

For Case B

Efficiency $= \dfrac{Wl + I^2R + CT}{Wm}$ where CT is the mechanical losses of L including belt loss.

In running the counter torque curves, the field of L must be held constant throughout, and readings must not be taken when accelerating.

Standard Efficiency and Power Factor tests consist in calculating the efficiency and power factor at any load from the general and special tests. See Figs. 76 and 77.

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Normal load heat run consists in running the motor under load until it has reached constant temperature and recording temperatures.

Standard overload heat run consists in bringing the machine to full load temperatures, then applying 50 per cent. overload for two hours, recording temperatures. Then apply 25 per
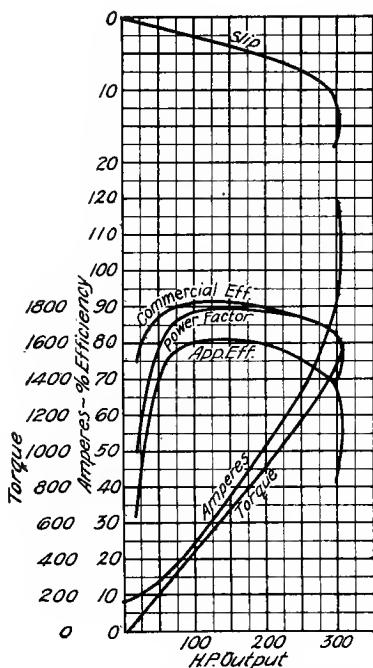
Fig. 77

CHARACTERISTIC CURVES OF A 100 KW., 2080 VOLT, 1200 R.P.M. 60 CYCLE, 3-PHASE INDUCTION MOTOR

cent. overload until constant temperature is reached, recording temperatures.

Special overload heat run consists in bringing the machine to full load temperatures, then applying the required overload for the specified time and recording the overload temperatures.

Short commercial run consists in a one-half hour heat run at 115 per cent. voltage at no load. Readings must be made

in all phases and in single phases separately, when running light tests are made. Starting tests should be made on Form L motors.

Long commercial test consists of tests taken at light loads and no load which will give approximately full load temperatures.

BLOWERS

Tests

COMPLETE TESTS consist of special tests and normal and maximum air delivery heat runs.

SPECIAL TESTS consist of general tests on driving motor, and air measurements to determine the delivery of blower.

GENERAL TESTS. General tests on the driving motor, taken from the standard report on a duplicate motor and air measurements, are made to determine the delivery of the blower.

NORMAL AIR DELIVERY HEAT RUN is made with normal air delivery from blower, until constant temperature of motor is obtained.

MAXIMUM AIR DELIVERY HEAT RUN is made with the blower giving a maximum air discharge for a specified time, or until the motor temperatures are constant.

ENDURANCE RUN. These tests are usually required by the Government and must be made in accordance with the specifications.

COMMERCIAL TESTS consist of the blower operating at maximum air discharge for a sufficient time to see that no electrical or mechanical faults develop.

Three methods of testing fans are in general used:

1. *The Double Pitot Tube Method*, used in testing Government fans.

2. *The Cone Method*, sometimes used for testing ordinary commercial fans for purposes other than government work or transformer ventilation.

3. *The Box Method*, used for testing fans for ventilating air blast transformers.

1. DOUBLE PITOT TUBE OR GOVERNMENT METHOD

This test is made in accordance with Government specifications issued by the Navy Department under the cognizance of Bureau of Construction and Repair.

Use of Air Table

When taking a fan test the room temperature of the air near the fan should be taken by two Fahrenheit thermometers, one hanging free in the air, and the other hanging with the bulb wrapped in thin cloth saturated with water, by placing the end of the cloth in a small receptacle filled with water. The temperature of the water must be the maximum temperature that it will naturally attain in the room. Corrected barometer reading must also be recorded on the test sheet.

The method of finding the weight of air from the air tables, mentioned in the specifications, is as follows: On the page containing the dry bulb reading as given by the test sheet, note the corresponding barometer reading. In the column under the dry bulb temperature and opposite the barometer

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reading, the corresponding weight of air is given. The weight of air found in the table must then be corrected to correspond with the corrected barometer reading found in test. This correction will be found in the second line from the top of the page. Correction must also be made for the difference between the wet and dry bulb temperatures by adding to the weight of air already obtained the number in the third sub-division of the column under the dry bulb temperature, which corresponds to the difference between the wet and dry bulb reading. This reading will be found in the second sub-division of the column.

Example: Given barometer reading   30.15 in.
           Dry bulb reading 67° F.
           Wet bulb reading 59° F.

Under the column showing the dry bulb temperature of 67° and opposite the barometer reading of 30.1, the weight of air is given as .07517. The addition for each .01 of an inch of barometer is given as 2.6 in the second line from the top of the page. Multiply this by 5, *viz.*, by the excess of the corrected barometer reading over that selected in the table; the result is 13, which must be added to the weight of air previously found. The wet bulb depression is the difference between 67° and 59°, *viz.*, 8° The number opposite 8 is 23. This must also be added, making the total weight of air .07553. All pressure readings should be corrected for standard air (see page 196) by multiplying the actual pressure obtained by the ratio of the weight of standard air to the weight of air at the time of test. The readings of horse-power input to the fan should also be multiplied by this ratio.

Pressure and Horse-Power Curves by Double Tube Method

A pressure curve may be taken by the double tube method as follows:

The opening at the outer end of the discharge pipe should be closed and pressure and power readings taken. Under this condition the static and impact pressures should be exactly the same, since no air passes through the fan. Readings should be taken by increasing the opening by equal increments from closed to wide open, measuring the opening each time. The speed of the fan should be held constant throughout the test. The air readings and electrical input readings should be taken simultaneously.

It will be noted that in a test which is made with a pipe on the discharge side of the fan, the reading of the impact tube is always greater than the static reading. If the pipe is on the suction side, the reverse will be true. The difference between the two readings is the velocity head. The Pitot tube should point against the stream of air in either case.

If readings afe taken by means of a U tube, the reading of both sides of the tube should be given on the test sheet. The test sheet should always specify whether the readings were

taken by the U tube or by a manometer. If by a manometer, the manometer constant should be recorded and must always be used in working up the test.

Calculation of Fan Tests by the Double Tube Method

A fan test of this kind should be worked up in the following form on the standard column paper provided. The abbreviations given should always be used to avoid confusion.

FAN E.C. 20.　　　NO. 1164.　　　FEB. 10, 1909.
Motor Rating CQ 2–2 H.P. – 1175 – 125 V.
Double Tube Test, Taken at 1000 R.P.M.

No.	h''	h'	h'''	"f"	V	Q	$h''+$"f"	$h'+$"f"	Air H.P.	Fan H.P.	Eff.
1											
2											
3											
4											

Wet Bulb.....................°F.　Barometer.............................in.
Dry Bulb.....................°F.　Wt. of Air.............................lb.

$$\text{"}f\text{"} = \frac{L \times h'''}{D \times 39}$$

Effective area of Pipe =
　　　. . . . . .Sq. Ft.

The first column gives the number of the reading.

The second and third show the impact and static readings taken from the test sheet and corrected for standard air.

The fourth column shows the velocity head or the difference between h' and h''

The fifth column is friction which must be calculated from the velocity head by the formula "f" $=\dfrac{L \times h''}{D \times 39}$, where "$f$" equals friction loss in inches of water, L is the length of pipe between the fan and the Pitot tube, D is the diameter of the pipe, if it is round, or is the average of the width and depth if it is square or nearly square. L and D must always be of the same denomination The friction loss should be added to both the static and impact readings before the curves are plotted, but it does not affect volume.

The sixth column showing the air velocity may be obtained from the curves shown on prints C–4487–A, B, C, and D. It may be also obtained from the formula $V = 1097 \sqrt{\dfrac{h'''}{w}}$

The volume must be given in the seventh column. It is obtained by multiplying the velocities given in column six by the effective area of the pipe, *i.e.*, 91 per cent. of the actual area.

The horse-power in the air can be calculated from the formulæ:

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$$\text{Air H.P.} = \frac{P \times Q}{33000} \quad \text{or} \quad \frac{P \times Q}{3367} \quad \text{or} \quad \frac{h \times Q}{6346}$$

The horse-power input to the fan is the horse-power output of the motor.

Unless instructions are issued to the contrary, all fan tests for government work should be plotted with pounds per sq. ft., horse-power input to fan, and efficiency as ordinates, and volume in cu. ft. per minute as abscissæ. Both static and impact pressure should be plotted.

The tester should carefully date and sign each test sheet, and should include sufficient data to distinguish all sheets used on the same test. For instance, electrical readings are usually placed on one sheet and fan pressure readings on another, therefore each of these sheets should state the name or number, or both, of the fan, the rating of the motor, the speed at which the test was taken and the method used. The Calculating Room must see that this data is placed on the Calculation Sheet.

The sheet on which the curves are plotted should give the name, type and number of fan, rating of the motor, speed at which the test was taken, and the method employed. Curves should always be plotted across the width of the sheet.

2. CONE METHOD OF TEST

In the cone method of test an adapter is used, where it is necessary, to change the fan outlet from rectangular to circular, a cone being placed on the circular end. This cone is made up of sections about one foot in length, the sides of which slope about two inches to the foot. Readings are taken by a single Pitot tube, the open end of which is held flush with the opening in the outer end of the cone and pointed against the stream of air. Pressure is registered as before, by a manometer or U tube. The readings are taken, one at the top, one at the bottom, and one at each side of the cone at a distance from the edge of the pipe of about $\frac{1}{8}$ of the diameter of the opening. A reading is also taken in the center of the cone opening. The average of these five readings represents the impact pressure produced by the fan, and is taken as the velocity head. The velocity may be obtained from the curve or from the formula given for the double tube test.

The static pressure may be obtained as follows: Divide the volume of each opening by the area of the fan opening, which gives the outlet velocity V_1. The corresponding velocity head can then be obtained from the curve. The velocity head subtracted from the impact pressure gives the static pressure. The static pressure should be plotted as well as the impact pressure.

These tests should be plotted with pressures in inches of water, h.p. inputs to the fan, and efficiencies, as ordinates, and volumes as abscissæ.

The following form should be used for tabulating the results of calculations:

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Motor Rating CQ 2–2 H.P.–1175–125 V.

Cone Test taken at 1000 R.P.M.

No.	h''	V	A_e	Q	V_1	h'''	h'	Air H.P.	Fan H.P.	Eff.
1										
2										
3										

Wet Bulb..................°F. Barometer ....in.

Dry Bulb..... ....°F. Wt of Air. .... lb.

After the curves are plotted, the efficiency, as given by the calculations, should be checked with the efficiency obtained from the curves. This will correct any discrepancy between the efficiencies as obtained from the curve and as calculated.

3. THE BOX METHOD

The box method of testing fans is as follows:

The fan is arranged to discharge directly into a large box which has a sufficient capacity to reduce the air velocity to a minimum. An opening is made in the side of the box at right angles to the opening into which the fan discharges, and cones are attached similar to those used in the cone test. Readings are taken by the same method and readings should also be taken of the box pressure by a U tube connected to a pipe inserted through a hole in the side of the box. This end of the pipe should be flush with the inside of the box to avoid eddy currents. The pressure shown by this pipe will be somewhat higher than that registered at the end of the cone, and both pressures should be corrected for standard air and plotted on the final curve sheet.

The volume must be calculated as in the cone test, but the pressure obtained in the box is taken as the static pressure produced by the fan, since the velocity head is lost in the box. To obtain the impact pressure the volume obtained should be divided by the area of the opening of the fan, and the corresponding velocity head taken from the curve. This velocity head should be added to the static pressure shown by the cone readings. For transformer ventilation it is customary to calculate the pressure in ounces, measured at the cone opening.

The following form should be used in tabulating the calculations:

No.	h'	p	V	Ae	Q	V_1	h'''	h''	Air H.P.	Fan H.P.	Eff.
1											
2											
3											
4											

Wet Bulb............ ....°F.　Barometer...........................in.
Dry Bulb...................°F.　Wt. of Air.............................lb.

Fan h.p. should be calculated from the static pressure and the efficiency obtained will be the static efficiency.

FORMULÆ FOR BLOWER TESTS

H = Head of air in feet.
h = Head of water in inches shown by manometer.
h' = Static head; h'' = impact head; $h''' = h'' - h'$ = velocity head.

Weight of water = 62.36 lbs. per cu. ft. at 62° F.

Weight of column of water 1 ft. sq., 1 in. high, 5.20 lbs. at 62° F.

Weight of cu. ft. of air at 30 in. Bar., 70° F., 70 per cent. humidity = .07465 lb.

This is taken as "Standard Air."

Weight of air under other conditions, neglecting humidity =

$\dfrac{.07465 \times B \times 530}{30 \times 460 + t°}$ for Fahrenheit, or $\dfrac{.07465 \times B \times 2941}{30 \times 273 + t°}$ for centigrade.

V = Velocity of air in feet per minute.
v = Velocity of air in feet per second.
Q = Volume in cubic feet per minute.
P = Pressure of air in lbs. per sq. ft.

p = Pressure of air in ounces per sq. in. = $\dfrac{h}{1.732}$ = .577 h

"f" = Loss of head in inches due to friction in pipes = $\dfrac{L \times h'''}{D \times 38.8}$

L = Length of pipe between the fan and the Pitot tube.
D = Diameter of pipe, if it is round; or = the average of the width and depth, if it is square or nearly square.
P = $5.20 \times h - 9\ p$
A = Area of pipe in sq. ft. A_e = Effective area of pipe = $A \times K$
H = $5.20 \times \dfrac{h}{w}$ = $69.73 \times h$ for standard air.

$$v = \sqrt{2g\overline{H'''}} = 8.02\sqrt{\overline{H'''}} = 8.02\sqrt{\frac{5.2 \times h'''}{w}} = 18.28\sqrt{\frac{h'''}{w}}$$

$$V = 481.2\sqrt{\overline{H'''}} = 1097\sqrt{\frac{h'''}{w}} = 4015\sqrt{h'''} \text{ for Std. Air.}$$

$$Vol. = 1097\sqrt{\frac{h'''}{w}} \times KA = \begin{matrix} :3654 \times A\sqrt{h'''} \text{ for } K = .91: \\ :3774 \times A\sqrt{h'''} \text{ for } K = .94: \end{matrix}$$
for Std. Air.

K = .94 for the Cone Method.

K = .91 for double Pitot tube or Navy method.

For a given opening pressure varies as the square of the speed of the blower.

Volume varies as the square root of the pressure, hence, directly as the speed.

Air h.p. varies as the cube of the speed.

$$\text{Eff.} = \text{Efficiency} = \frac{\text{Air H.P.}}{\text{Fan H.P.}}$$

AIR COMPRESSORS

The preliminary tests made on Air Compressors consist of resistance measurements, high potential, running light, cold capacity and noise tests, and mechanical inspection of pump gears and oiling systems.

In taking the running light or friction test the motor should be run, with the pump disconnected from the tank, at approximately full load speed until the friction has reached a constant value. The voltage, current and speed should then be noted and recorded. The friction value should be checked with that given in Standing Instructions 6164–B, and if it is excessive the defect must be remedied before the test is continued.

Cold capacity test should be made in the following manner, the pump being connected to tank No. 1. (See Fig. 78.) With the rated voltage across the motor, it is run light until the friction becomes constant, then the pressure in tank No. 1 is increased to 90 lbs. gauge, and led into tank No. 2 at such a rate that 90 lbs. is maintained in tank No. 1. The time from first opening the intermediate valve until the gauge of No. 2 reads 90 pounds should be noted, as well as the total number of armature revolutions and the current required. This should be done three times to obtain an average reading.

All compressors should be carefully observed for unnecessary noise in operation due to gears or cranks. If defects are found, they must be reported at once.

Complete tests consist of special tests and special heat runs.

Special tests consist of core loss, saturation, motor friction, speed curves, pump capacity and pump and gear friction.

Speed curves should be taken in both directions at a voltage which prevents flashing at the commutator when the motor is reversed. Another speed curve should be taken, in the operating direction, at 550 volts (unless otherwise specified) on pump loads, in which the tank pressure varies from 0 to 140 lbs. During this test, or by making an independent test, capacities of the compressor should be taken, while pumping against pressures varying from 0 to 140 lbs. The speed curve should be plotted in the same manner as that of a railway motor. From the capacity test, one curve should be plotted of tank pressure and pump speed against amperes as abscissæ. Another should be plotted of watt hours per cubic feet of free air and cubic feet per minute of free air against tank pressure. The field of the motor should now be separately excited, the gears removed and a friction and core loss test taken. The armature should be run on a voltage which will give speed and field excitation corresponding to the speed curve. A curve is then plotted of watts to amperes.

The friction of the motor should be determined by running it light as a series motor at a voltage low enough to give the same range in speed. A curve of watts against speed should then be plotted.

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From the above curves, the core loss alone can be determined and plotted in watts against amperes.

The results may then be calculated as in the case of a railway motor, the I^2R being corrected for 75° C. rise in temperature.

General tests consist of sufficient preliminary tests of the machine tested to warrant engineering approval of the type for production.

SPECIAL HEAT RUN consists of several heat runs made with the compressor, operating with different time cycles. Usually four successive tests should be made as follows:
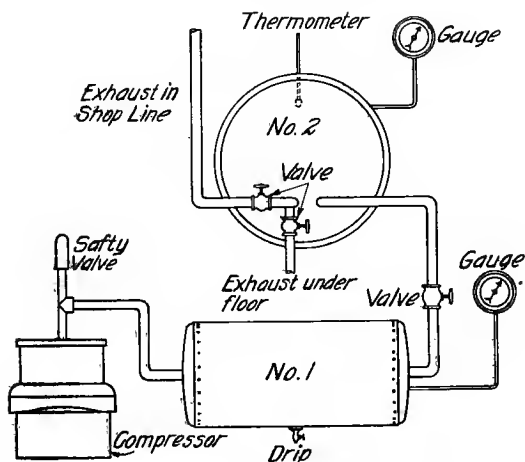
Fig. 78
TANK CONNECTIONS FOR AIR COMPRESSOR TEST

No. 1.   3 minutes on and 7 minutes off repeated to end of test.

No. 2.   5 minutes on and 5 minutes off repeated to end of test.

No. 3.   7 minutes on and 3 minutes off repeated to end of test.

No. 4.   Continuously.

The machine should be allowed to stand idle not less than eight hours between each test, and in each case the test should be continued either until the temperatures of the armature and field become constant or until the temperature rise amounts to 125° C. by resistance measurement. The commutator door and all covers should be kept closed during the test, and unless otherwise specified, the machine should operate at 550 volts and pump against 90 lb. gauge pressure. Temperatures and

resistances should be taken at regular intervals throughout the run, and at the end final temperatures and resistances should be taken.

Four curves, obtained from the results of the four tests should be drawn on one sheet of the temperature rise by thermometer of the field coil against time as abscissæ. Over these curves should be drawn curves of temperature rise by resistance measurement.

A similar set of curves should be made for the armature on another sheet. On a third sheet should be plotted a series of curves of thermometer temperature rise at the end of each hour against percentage of operating time.

In connection with run No. 4, the compressor capacity should be taken cold and as often as possible throughout the test. Temperatures should be taken every five minutes on the cylinder and exhaust chambers. The temperature rise of cylinder and exhaust chambers, watt hours per cubic foot of free air, and cubic feet of free air per minute should be plotted against time. The volume and temperature of the air in the measuring tank must be known to determine watt hours per cubic foot.

COMMERCIAL TESTS consist of the compressor running light for one hour, followed by a full load run for thirty minutes, after which the hot capacity test is made. This test is made in the same way as the cold capacity test. A speed greater than that specified in Standing Instructions 7884 indicates leaks or poor valves. This trouble should be remedied at once.

TRANSFORMER TESTS
CONSTANT POTENTIAL TRANSFORMERS

Tests

COMPLETE TESTS on Constant Potential Transformers consist of special tests, normal and overload heat runs and insulation tests.

SPECIAL TESTS consist of polarity, ratio, taps, resistance, core loss and impedance curves with wattmeters.

SHORT COMMERCIAL TESTS consist of polarity, ratio, taps, resistance, core loss at normal and ¾ normal voltage, impedance at normal amperes with wattmeters, parallel runs, and insulation tests.

LONG COMMERCIAL TESTS consist of polarity, ratio, taps, resistance, core loss at normal and ¾ normal voltage, impedance at normal amperes with wattmeters, parallel run, and heat runs at normal load.

NORMAL LOAD HEAT RUN consists in operating the transformer until it shows constant temperature at normal volts and amperes.

OVERLOAD HEAT RUN consists in operating the transformer until it has reached normal load temperature and then applying the required overload for the specified time.

EFFICIENCY TESTS are calculated from special tests.

REGULATION TESTS are calculated from special tests.

INSULATION TESTS consist in applying high potential between the high potential winding and the low potential winding and ground (the low potential winding being connected to ground), and between the low potential winding and ground, also operating the transformer at double potential for one minute, and at 50 per cent. above normal potential for five (5) minutes.

Special Tests

The following order of tests has been found most convenient: —Cold resistance ; polarity; ratio and checking of taps; impedance; core loss and exciting current; parallel run; insulation tests; double potential for one minute; one and one-half potential for five minutes, and high potential test.

Transformers built for potentials above 50,000 volts should have the double potential test taken after the high potential test.

As many of the tests on the different types are very nearly alike, a complete discussion will be given on the first type and a shorter one on the others.

Single-Phase Air Blast, Type AB Transformers

As soon as a transformer, or group of transformers, are to be tested, the Engineering Notices should be consulted for guarantees, ratings and operating conditions. If the transformer has taps, the proper sketch and winding specification should be obtained to show the various voltages required. The transformer must be properly placed over the pit, and the supporting boards

must be sufficiently strong; otherwise the transformer may fall into the pit, and injure any one who may be stationed under it. No opening should be left through which air can escape and influence readings of the thermometer on the transformer iron. When the transformer is in place, a careful inspection should be made, making note of any defect, no matter how slight. The top of the transformer should be examined for the metal tags that may have been left by the assemblers. If any serious defects are found, they should be reported at once, to allow them to be repaired immediately. After the points given above have been noted. the record sheet should be filled out as far as possible.

The order of tests may be varied if found necessary, *e.g*, a resistance measuring set is not always available; then ratio and taps may be taken. If the core loss alternator is in use, some other test must be made to prevent loss of time. Usually two or more transformers of the same rating are tested at once. In the following, two or three transformers are considered.

Cold Resistance

As the temperature guarantee of the windings specifies that the increase in resistance method be used, considerable care must be taken in measuring resistances, as follows:—Place a thermometer on the coils of each transformer, and send from 10 to 15 per cent. full load current through the transformer coils. This is generally the proper amount for two or four transformers. The ammeter should not read below the center of the scale. The current must never be sufficient to appreciably heat the windings while taking resistance. In very low voltage secondary windings use about 40 amperes, as this current usually gives sufficient drop to be read on the voltmeter. The drop lines must not include the resistance of any temporary connections. Adjust the resistance in the box until the reading comes about the middle of the scale of the voltmeter. Considerable time will be saved by short circuiting the secondary while the primary is being measured, and by short circuiting the primary while the secondary is being measured. In measuring secondary resistances, especially when low, the contacts for the voltmeter leads should be carefully cleaned with sandpaper.

Take three (3) readings on each coil, holding about the same current. It is far better to allow the ammeter to vary slightly, than to try to hold exactly the same reading, as the observer is likely to be prejudiced. In recording results, always record the numbers of both meters, their constants and dates of calibration, together with the voltmeter resistance, the resistance of the drop lines and the resistance in the box and its number. Record the temperatures of the coils. If the transformers have more than one primary and secondary coil, a clear sketch should be made and the coil so marked as to prevent confusion. In recording results, the value of the unit deflection should be noted and readings should be pointed off accordingly.

Readings should be taken as rapidly as is consistent with accuracy. The method of calculating rise in temperature by increase of resistance is explained under heat runs.

Polarity

The polarity test is taken since it gives the only means of readily determining the connections required for transformers in banks, for instance, several transformers in parallel. When transformers are connected for measurement of resistance, the polarity test can readily be made with a special voltmeter. Select one transformer as a standard. When several are in test at once, one near the middle of the group should be chosen as it will be safer and more convenient when the transformers are run in parallel. With direct current passing through one winding of the transformer, connect the special voltmeter across the terminals to get a positive deflection. Then transfer the drop lines to the corresponding terminals of the other winding, and break the current in the first winding. If the polarity is correct a positive kick will be obtained. In making this test have sufficient resistance in series with the voltmeter so that it will not be damaged. For standard polarity of AB transformer see Figs. 79, 80 and 81. The terminals marked positive should be of the same polarity.

It is not necessary to take polarity on more than one transformer of a group, as the parallel run will show whether or not they all have the same polarity. In taking polarity on special transformers a clear sketch should be made showing the polarity. For tap polarity see "Ratio" and "Checking Taps."

Ratio

The ratio of a transformer is the ratio of the primary voltage to secondary voltage, and should be the same as the numerical ratio of primary turns to secondary turns. The usual method is to apply about one hundred volts to the secondary winding and read the primary voltage, stepping it down with a suitable potential transformer. The ratio of the potential transformer should be as nearly as possible that of the transformer in test. The potential transformer must be operated at normal frequency and voltage, otherwise the ratio will be unsatisfactory. In very small transformers the voltage should be applied to the primary windings.

When the ratio of the potential transformer is very nearly that of the transformer in test, the voltmeters should be interchanged after five readings have been taken. When this is done it is not necessary to correct voltmeter readings from curves, as the errors will appear in both columns and be neutralized. In any ratio at least five readings should be taken, and the result carefully calculated. If the ratio by test varies more than *one* per cent. from the ratio of voltage, check the ratio of turns. If the ratios of voltage and turns agree, repeat the ratio with the same meters; if still out, repeat with an entirely different

set of meters and potential transformer. If the ratio is still
out, the transformer is wrong. Try the ratio on another one.
If the ratio, however, should be correct when the second set
of meters is used, use a third set and check again. If the second
and third sets of meters give a correct ratio, record both sets
of readings.
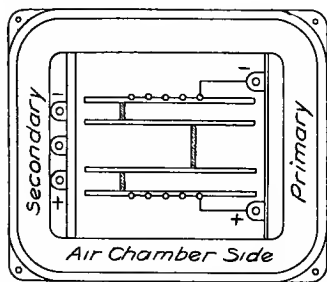
Bottom Looking Up
Primary and Secondary Leads
Both Brought out in the Base

Fig. 79

Bottom Looking Up

Primary and Secondary
Leads Brought out at Top
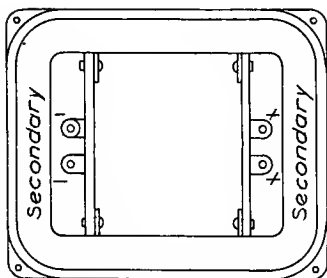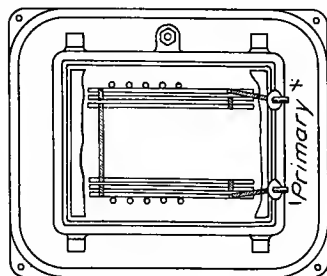
Fig. 80

Top
Primary Leads Brought out
at Top and Secondaries at
Bottom

Fig. 81

CONNECTIONS FOR POLARITY TEST

In taking ratio on transformers with taps or a dial switch,
note whether or not full windings were used. If the transformer
has more than one primary or secondary coil, note whether
the coils are in series or multiple. The ratio must check within
one per cent. of the ratio of turns. It is not necessary to take

ratio on more than one of a group, as the parallel run will determine whether they all have the same ratio. In recording ratio, record the date of calibration of meters and number and ratio of the potential transformer used. Also record the average of readings, the correction and actual ratio obtained. This will be a check on the Calculating Department.

Checking Taps

Nearly all transformers are provided with taps in one or both windings, so that a slight change in ratio or low voltage
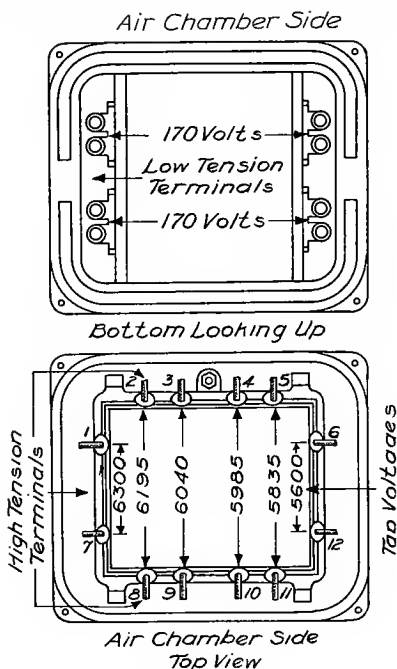
Fig. 82
TAPS

for starting may be obtained. Before checking taps, procure the proper winding specification and sketch. Taps are easily checked by applying a certain voltage per turn to the low tension winding and reading the voltage between the terminals of the winding and the first tap; then between successive taps on the same coil. In some cases it is equally satisfactory to apply full potential to one winding and read the voltage between adjacent taps. This is done on dial switch transformers.

The method can best be explained by an example. Take an AB-25-400-6300/6195/6048/5985/5835/5600-170, winding specification No. 21,435. The primary winding has six coils connected in series. These coils have 43 turns each with inside and outside ends. This is called a single section coil. The secondary winding consists of six coils, connected in multiple, with 7 turns each. Taps are brought out of the primary coils P–1 and P–6 at the ending of the 29th, 34th, 38th and 41st turns from the inside end. This gives tap turns of $43 - 41 = 2$, $41 - 38 = 3$, $38 - 37 = 1$, $37 - 34 = 3$, $34 - 29 = 5$ turns. Since the secondary winding has four coil terminal blocks, we can connect the secondary coils in series, giving 14 turns. Apply 5 volts per turn $= 70$ volts to the secondary (Fig. 82), and read volts $(1-2) = 10$, $(2-3) = 15$, $(3-4) = 5$, $(4-5) = 15$, $(5-6) = 25$. The same readings will be obtained on the other side of the primary winding. These turns must be checked with voltages required by the sketch. $(1-7)$ should be O.K. from the ratio test. The
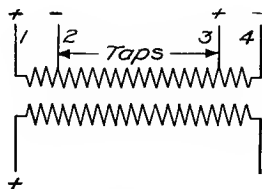
Fig. 83
TAPS

volts per turn at normal potential $= \dfrac{170}{7} = 24.2$ volts. In changing from $(1-7)$ to $(2-8)$ four turns are cut out of the primary winding, and the primary voltage is decreased by $6300 - 6195 = 105$ volts. Multiplying 24.2 by 4, 96.8, is obtained which is as near 105 as possible, unless a tap be brought out at a half turn, which is seldom done. Changing to $(3-9)$, six turns are cut out, and the primary voltage is decreased by $6195 - 6040 = 155$ volts. Now $6 \times 24.2 = 149.2$, which is near enough to 155. The remainder of the taps should be checked in the same manner.

Great care should be taken in handling the voltmeter connected to the taps, for while the voltmeter reading is low, the circuit to which it is connected may be several thousand volts above ground. If the opposite end of the circuit be grounded, a severe shock may be obtained from the meter.

In checking 50 per cent. taps, one meter should be used as a check and another to read the voltage across each half of the winding; the readings being taken first on one side and then on the other, holding the same reading on the check.

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Always make a neat sketch showing the position of the taps. On transformers with only one tap on each end, it is often necessary to check its location by polarity. (See Fig. 83.) With direct current flowing through the secondary take polarity (1–4), (1–2) and (3–4). If all the deflections are in the same direction, the taps are properly brought out. If some are reversed, the tap and line lead are interchanged. In case a tap is very much out, it should be reported at once to avoid unnecessary work.

In filling out sheets always note the number of secondary turns used and the number of turns between the various taps; also the sketch number.

Impedance

The expression $I = \frac{E}{R}$ for continuous current circuits is replaced in alternating current circuits by the equivalent expression $I = \frac{E}{\sqrt{R^2 + (2\pi nL)^2}}$ where I is the current, E the impressed
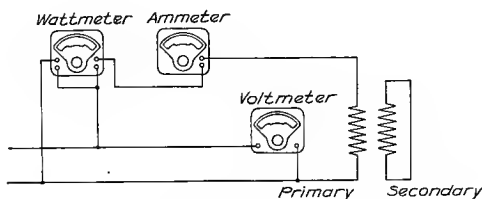
Fig. 84
CONNECTIONS FOR IMPEDANCE TEST

e.m.f., n the frequency, L the coefficient of self-induction and R the effective resistance of the circuit. For commercial purposes R may be considered as the ohmic resistance. The expression $\sqrt{R^2 + (2\pi nL)^2}$ is known as the impedance of the circuit and is defined as the apparent resistance of a circuit containing ohmic resistance and self-induction. The term $2\pi nL$ is called the reactance of the circuit.

The impedance of a transformer is measured by short circuiting one of the windings and impressing an alternating e.m.f. on the other winding and taking simultaneous readings of amperes, volts, watts and frequency. The impedance of transformers should be carefully measured for the following reasons. Transformers operating in multiple divide the load inversely as their impedance voltage; *i.e.*, the one having the higher impedance will take the smaller part of the load and *vice versa*. When transformers of different types are operated in multiple the impedance of one transformer must sometimes be increased by

putting a reactive coil in the secondary circuit, and adjusting until the desired impedance is obtained.

Impedance tests show whether a given arrangement of coils is satisfactory or not. If the arrangement is not satisfactory, excessive magnetic leakage will take place, and high impedance voltage result. The impedance watts will also be high, due to excessive eddy currents in the copper. Since regulation depends upon impedance to a great extent, a low impedance is very necessary for close regulation.

The impedance voltage of transformers usually varies from 1 to 4 per cent., although it may be as high as 6 to 7 per cent. The impedance watts usually do not exceed 1 to 1½ per cent. of the total capacity of the transformer and will be more than
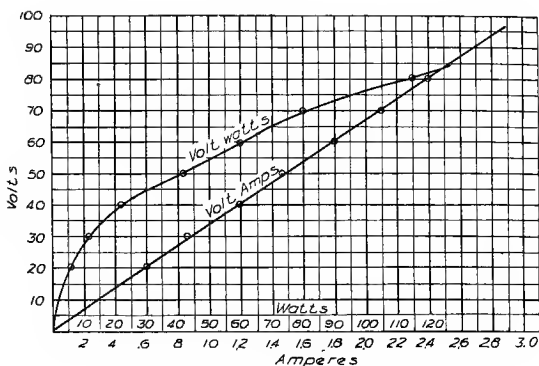
Fig. 85
IMPEDANCE CURVE

the calculated I^2R on account of eddy current losses in the copper.

The following method should be followed in making an impedance test. Place a thermometer on the coils to obtain the temperatures. Make a good short circuit on one winding, using as short a cable as possible, and of ample cross section so that no appreciable losses will occur. Calculate the full load current by dividing the watts capacity by the maximum voltage of the winding in which the meters are placed, unless the engineering notices call for tests under different conditions. Select suitable meters and make connections as shown in Fig. 84. Connect to the alternator through a suitable transformer.

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The alternator must be operated at as near normal voltage as possible when the normal impedance reading is taken.

Take a curve of ten points, starting at 50 per cent. and raising to 125 per cent. full load, holding the speed constant and taking simultaneous readings of amperes, volts and watts. It is essential that the speed be exactly right, as the reactance varies directly with the frequency. This curve should be plotted after the readings are taken (not as they are taken) to see if the curve is smooth; if the curve is not, check it at once. Plot volts as ordinates and watts and amperes as abscissæ. The volt-ampere curve should be a straight line, the volt-watt curve should be a parabola. For example see Fig. 85. In taking the curve it is more satisfactory if meters are selected so that no change is necessary throughout the curve. On the record sheet, note the type of alternator used, temperature of transformer coils, numbers, constants and dates of calibration of all meters used. If a potential transformer is used, record its number and ratio. Also, state plainly the hour at which the test is taken.
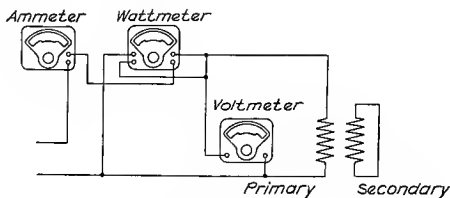
Fig. 86
CONNECTIONS FOR CORE LOSS TEST

The connections shown in Fig. 84 are used in preference to those shown in Fig. 86, as in Fig. 86 the losses of the voltmeter and of the potential coil of the wattmeter are included in the reading of the wattmeter. In Fig. 84 the only extra loss is that in the current coils of the ammeter and wattmeter, and that is negligible.

A potential transformer or multiplier should be used with a wattmeter when the voltage exceeds 150 volts. It will be noted that the lower binding posts on Thomson wattmeters must be connected together when neither a potential nor current transformer is used and if the voltage of the circuit is above 2000 volts, they should be connected by a small fuse wire. The secondary of the potential transformer should not be grounded, however, unless a current transformer is used. The adjacent ends of the current and potential coils are connected to these binding posts, and, unless they are connected to the same side of the line, there is danger of breaking down the insulation between the coils and burning out the wattmeter. Above 2000 volts the fuse wire is used to avoid electrostatic effects.

Core Loss and Exciting Current

When a transformer is connected to a source of alternating electromotive force, a loss of energy takes place in the iron, due to cyclic reversals of magnetic flux. This loss of energy is known as the core loss. The core loss depends on the wave form of the impressed e.m.f., a peaked wave giving somewhat lower core losses than a flat wave. It is not uncommon to find alternators having such a peaked wave form, that the core loss obtained with the transformer tested from them, is 5 to 10 per cent. less than that obtained with the transformer tested from a generator giving a true sine wave. On the other hand some generators have a very flat wave form, so that the core loss obtained will be greater than that obtained when sine wave is used. The core loss test is similar to the impedance test, except that voltage is applied to one winding, the others being open circuited. Voltage is always to be applied to the low potential winding to avoid reading meters in high potential circuits. Core loss should always be taken from a sine wave alternator, and transformer connections should be made so that it is operated at normal excitation when normal potential reading of core loss is taken.

Be sure to place the high tension leads so that no one can come in contact with them and that there is no danger of short circuit. The instruments should be so placed that they have no influence on one another, and are not affected by any stray field.

A core loss curve should be taken starting at 50 per cent. of rated potential and taking about ten (10) points to 25 per cent. above rated potential. Hold the frequency constant and vary the voltage, taking simultaneous readings of the excitation amperes and watts core loss. Do not plot the curve as each reading is taken, but as soon as all are finished. If the curve is not smooth, repeat it. The curve will be more satisfactory if meters can be so selected that no change is necessary throughout the curve. Record all meter numbers, their constants and date of calibration, temperature of iron and numbers and ratios of potential transformers or of multipliers. Wherever possible, use the wattmeter without a potential transformer or multiplier, by connecting the transformer for the lowest potential, as this will give more reliable results.

When the normal voltage of either winding is above 5000 volts it is often more satisfactory to take core loss indirectly; that is, to read input into the secondary of a transformer used to step up to voltage of the transformer in test. This step-up transformer should have ratio, resistance and core loss curve carefully taken.

Connect the primary of the step-up transformer to the secondary of the transformer in test. Put a low reading ammeter in the circuit to read the exciting current. Read volts, watts

and amperes in the secondary of the step-up transformer as usual. In calculating the actual core loss subtract the I^2R and core loss of the step-up transformer from the total wattmeter reading. While this method has its disadvantages it is almost as accurate as using a potential transformer of large ratio and a current transformer, and is certainly much safer. Connections for this test are shown in Fig. 87.

Parallel Run

The discussion of parallel runs is given here rather than with the discussion of ratio and polarity because heat runs are next in order and excitation voltage must now be provided.

Having previously tested the ratio and polarity on one of the group of transformers, the parallel run can be made and the polarity of the others can be checked with the one tested, also the ratio of the remaining transformers. If the transformers differ in ratio by 1/10 of one per cent. it will be shown in the parallel run, because the test is made at the full potential of the transformer. If a transformer is one turn out, a difference of voltage between the two transformers of from 15 to 40
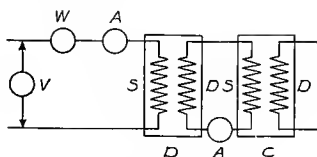
Fig. 87
CONNECTIONS FOR CORE LOSS TEST

volts will be shown, depending upon the size of the transformer. This potential gives quite a spark and the exact amount of voltage difference may be determined by connecting a voltmeter between the two transformers.

The connections for the parallel run are shown in Fig. 88, No. 2 being the standard transformer, the one on which polarity and ratio have been taken. Only two transformers must be connected at the same time, for if voltage is on the entire set, there is the more danger of some one coming in contact with the primary leads. Connect two of the transformers as shown in Fig. 88, making one side of the primary connections permanent, and arranging so that the other side may be completed with a small fuse wire of not over 3 ampere capacity. One end of this fuse wire should be carefully fastened to one end of a clean dry stick about two feet long so that the fuse wire may be handled without danger. Close the secondary switches and note if voltage is on the transformers by noticing whether a small spark is obtained by touching the frame of one transformer

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with the fuse wire. Now excite the alternator, gradually bringing it up to normal potential. As soon as field is on the alternator, the man handling the fuse wire should begin tapping its loose end on the primary terminal of the other transformer. If no spark is seen the transformers will operate in parallel.

If a small spark appears connect a voltmeter in series and read the difference of voltage with normal potential on the transformers. If this voltage is more than $\frac{1}{4}$ per cent. of the rated voltage of the transformer, report it at once so that the wrong coil can be located and repairs made. Instead of reading the voltage, the exchange current may be read by connecting an ammeter in the circuit instead of the voltmeter. This current should not exceed 5 per cent. of the normal current. Continue

Fig. 88
CONNECTIONS FOR PARALLEL RUN

the parallel tests as above, until all the transformers have been run in parallel with the one selected as standard.

As soon as the parallel run is completed, see that it is properly recorded on the sheet, with the numbers of the transformer used as the standard. If the parallel run is satisfactory mark it "O.K." If the transformer has two circuits that may be operated either in series or parallel, the parallel test should be made on them by connecting the corresponding ends of the coils on one side together, completing the circuit by means of fuse wire, and applying full potential to the other winding of the transformer.

It is just as essential that the coils of a transformer operate in multiple satisfactorily as it is for two transformers to operate. If the parallel run is O.K., note the fact on the record sheet.

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Normal Load Heat Run

The heat test may be conducted in several ways, all of which are designed to approximate as nearly as possible the operating conditions of the transformers. A run with actual load might be made by using water rheostats, but, as this would be very expensive, some form of motor-generator method should be used. Fig. 89 shows the connections for testing two transformers by the motor-generator method. The secondaries of both transformers are connected in multiple, and then connected to an alternator, which supplies the core loss and exciting current. The primaries are connected in series and opposing each other. If the transformers have the same ratio, the voltage from A to B will be zero.

The secondary of an auxiliary transformer D is connected in series with the primaries of the transformer in test. Alternator E, connected to the primary of transformer D, supplies the
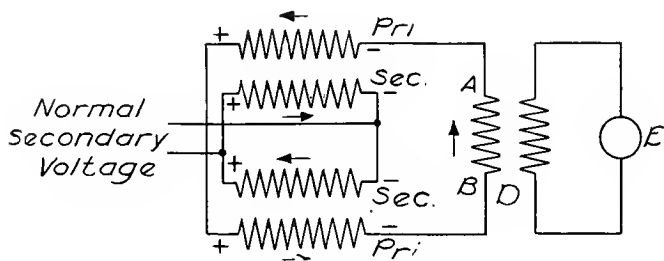
Fig. 89
CONNECTIONS FOR HEAT RUN

copper losses. The same method may be used for any even number of transformers; but it is not advisable to run more than six at a time. Fig. 90 shows connections for the heat run on three transformers. The primaries and secondaries are connected in delta. One of the delta connected circuits is opened and sufficient voltage is impressed to cause full load current to flow. The current circulates within the delta and is entirely independent of the secondary voltage. The two methods outlined above require only sufficient power to supply the losses.

In arranging for the heat run, see that the alternators and transformers are of sufficient capacity to carry the load. In calculating the current necessary to supply the iron losses, take the sum of the exciting currents of the transformers. If the transformers have several secondary coils connect them in series, so that when the heat run is completed no time will be lost in making connections for measuring hot resistance. If the engineering notice specifies the heat test to be made with secondaries in multiple to see if unbalancing of the load between

will cause any undue heating, then follow engineering instructions. Arrange so that the alternator supplying the core loss will operate at normal excitation. To calculate the voltage required to supply the load current add together the impedance voltages of the transformers. If possible, arrange to run the primaries in series if there are more than one. If the transformer is to have 50 per cent. overload test, add 50 per cent. to the voltage already obtained

Shop transformers should always be interposed between the primaries of the transformers in test and the alternators to prevent breaking down the armature and to avoid having high potentials on the switchboards. "Step" the voltage either down or up, or down and up again, depending upon circumstances; but always have transformers between the alternator and the primaries of the transformers in test. Having
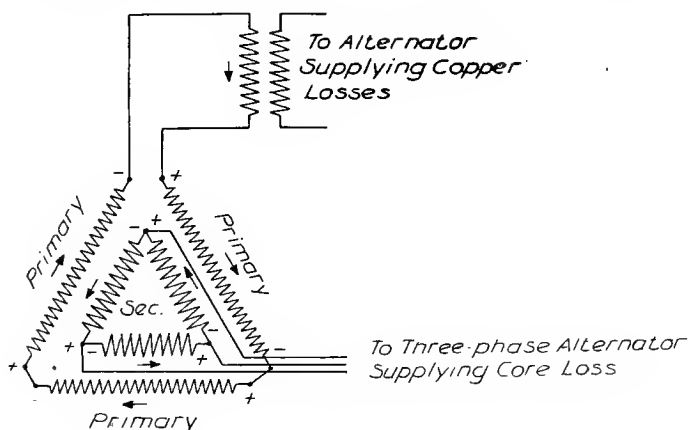
Fig. 90
CONNECTIONS FOR HEAT RUN

made connections, place a man on guard to prevent any one coming in contact with the wiring; then see if the proper load and overload can be obtained. There should be some resistance left in the field of the alternator so that as the alternator fields and the windings of the transformers heat up, the load can be kept normal.

If load can be obtained, open the field switch of the alternators and switches in their armature circuits. After making sure that no voltage is on the transformer, carefully tape up all connections, leaving places bare · for holding on "drop" lines. Arrange all lines so that they are not dangerous, put white tape about the transformers, and see that the frames are securely grounded. Now place spirit thermometers in the

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top of the transformer to read the temperature of the air escaping from the coils. Use two thermometers for the primary and two for the secondary windings, placing them about one inch above and just over the ducts between the coils. Also place two thermometers on the core to read the temperature of the iron, one near the top and one near the bottom, and two thermometers so as to read the temperature of the air escaping from the iron. The transformers can now be loaded. With the alternator running at proper speed the total exciting current of the transformers should be read. In this way the secondary voltage can be checked.

Air blast transformers are usually run at full load for 50 minutes without air, so as to heat them up and thus shorten the heat run. Some transformers cannot be operated for more than 20 minutes without air and they must be carefully watched to see that they do not get too hot. After the air blast is put on, it is usually necessary to keep the iron damper closed for some time to allow the core to heat up, as the copper heats much faster than the iron. The amount and pressure of air required depends on the guarantees as to temperature and to some extent on the voltage of the transformers. The large amount of insulation on the coils of high voltage transformers tends to retard radiation.

If transformers have "A" guarantees, that is, a maximum temperature rise of 40° C. at normal load, and 55° C. rise after 25 per cent. overload for two hours, the air should be adjusted to give about 35° rise on the copper and 40° rise on the iron. If the iron seems too hot, increase the air pressure, partially closing the top damper; if the copper is too hot, increase the pressure and partially close the lower damper.

If the transformers have "B" guarantees, that is, at normal rating, a maximum rise of 35° C. and after two hours at 50 per cent. overload, a rise of 55° C., the air should be adjusted to give about 30° rise on the copper and 35° rise on the iron. These adjustments should be carefully made during the first hours of the heat run.

When properly adjusted the transformers should run about four hours at a practically constant temperature. Place the thermometers for measuring the room temperature near the intake of the blower so as to get the temperature of air delivered to the transformers. Read all thermometers and take the resistance on one winding of each transformer every hour. Iron temperatures may be read while the transformers are under load, as the frames are grounded. If primary leads are brought out of the top of the machine, the voltage should be switched off so as not to endanger any one; if the transformers, however, are bottom connected these temperatures may be read while they are under load.

If it can be avoided, do not change the position of thermometers when taking readings. When ready to measure resistances, shut down the blower, take off the load and measure the resistances as rapidly as possible, so as not to allow the

transformers to cool off. One minute per transformer should be ample time for these readings. The rise by resistance is calculated as follows:

t = Cold temperature of coil.
T = Hot temperature of coil.
R_t = Cold resistance of coil.
R_T = Hot resistance of coil.

$$T = (238 + t)\frac{R_T}{R_t} - 238.$$

During the heat run a careful inspection should be made for loose laminations. If any transformers are found that rattle or buzz, due to loose iron, they should be plainly tagged and a chalk mark made on the core as near as possible to the point at which buzzing was heard. A note should also be made on the record sheet. The heat run and other tests should now be finished, except the double and high potential tests which must always be taken after any repairs.

It sometimes happens that the iron casings are loose and rattle. Tighten up all the screws, and if this does not stop the noise, strips of felt must be placed between the sheet iron casing and the cast iron corner castings, cap and base. If this defect is discovered during the first part of the heat run, it should be repaired before the heat run is continued; if not, repairs will be made after the heat run is finished. After such repairs always apply full voltage at normal frequency to see if they are satisfactory. If a motor-generator method cannot be used, the copper and iron heat runs may be taken separately.

To make a short circuit heat run; short circuit the secondary windings and apply normal current to the primary. When this test is finished and the hot resistance is taken, open circuit the primary, arranging the primary leads so that there is no danger of any one being injured, and apply normal voltage at proper frequency to the secondary until the iron temperatures are constant. Finish up the tests as if the heat run were taken by the motor-generator method. The same amount of air will be required and the heating will be practically the same as if both iron and copper were loaded at the same time.

At the end of the heat run measure all resistances carefully and read the thermometers. Additional help should be obtained from another testing stand in order that these resistances may be taken rapidly. The same care should be used as in taking cold resistances, and if any set of readings indicates a doubtful increase of resistance, the readings should be checked, using a different set of meters. If the work is properly conducted, ten minutes is ample time to take a complete set of resistance readings on four transformers. A careful inspection should be made of all soldered joints to see that there is no undue heating. In recording results be sure to properly identify the coils; otherwise much confusion is caused in calculating results.

The temperature rise by resistance should be checked by the head of the test or by one of his assistants before the next test is started. When no overload is specified, the transformers

must be run for 20 minutes at 50 per cent. overload current to test soldered joints. This test follows hot resistances.

Overload Heat Runs

Engineering instructions always specify the overload tests required. This test is ordinarily limited to two hours and is taken as a continuation of the normal load heat run. All temperatures are taken during the normal load heat run, primary resistance being measured hourly. All data is then ready for normal heat run except hot secondary resistance, which is usually omitted until after the overload heat run. In this way considerable time is saved which would otherwise be lost in reconnecting secondaries and heating up to normal load temperatures. Transformers with "A" guarantees will be run two hours at 25 per cent. overload, rise not to exceed 55° C. These with "B" guarantees will be run two hours at 50 per cent. overload, rise not to exceed 55° C.

Transformers are sometimes designed to run continuously at overloads, or may be guaranteed to operate at a certain kw. output at some power factor less than unity. Overload heat runs should be very carefully watched, particularly those of short duration. Special attention should be given to the length of the run, as the temperatures often rise very rapidly. At the finish of the heat run, record all temperatures and measure all resistances. The same air pressure should be used for the overload as for the normal load.

INSULATION TESTS

Double Potential Test

Double potential is applied to test the insulation between turns and between sections of the coils. Since it is impossible to obtain double voltage on a transformer at normal frequency, due to high density in the iron, the frequency must be increased. Apply twice the normal voltage for one minute, followed by one and one-half times normal voltage for five minutes. The last test is taken in order to discover any short circuits that might develop during the double potential test, and yet not become apparent in the short time that the double potential is applied. The primary bushings should be cleaned before the test and the transformer should be guarded to prevent accidents from any of the high voltage circuits. Any leakage or buzzing should be noted.

In applying and taking off the high potential, vary the alternator field gradually; that is, do not open the field switch with a jerk, as it is very likely to cause trouble. As soon as this test is taken, make the proper comments on the record sheet. In this test, as well as in the core loss and impedance test, the alternator supplying the voltage should be operated at as near normal voltage as possible, so as to avoid distortion of the wave form.

In case a transformer breaks down, locate the defective coil and mark it plainly. Then, in disassembling the machine,

the coil can be easily found and the cause of the defect ascertained, thus preventing a repetition of the breakdown.

High Potential Test

The application of a high potential to the insulation of a transformer is the *only* method for determining whether the dielectric strength is sufficient for continous operation. Mechanical examination amounts to little and measurement of insulation resistance is equally valueless, since insulation may show high resistance when measured by a voltmeter with low voltage, but offer comparatively little resistance to the passage of a high tension current.

The insulation test which should be applied to the windings of a transformer depends upon the voltage for which the transformer is designed. The voltage to be applied should always be obtained from Standing Instructions, or from Engineering Notices. In testing between the primary and the core or the secondary, the secondary should be grounded for the following reasons: In testing between one winding and the core, a potential strain is induced between the core and the other winding which may be much greater than the strain to which the insulation is subjected under normal operation, and greater, therefore, than it is designed to withstand. In testing between the primary and the core, the induced potential between the secondary and core may be several thousand volts, and the secondary may thus be broken down by an insulation test applied to the primary under conditions which would not exist in normal operation. During the test, all primary leads, as well as all secondary leads, must be connected together. If only one terminal of the transformer winding is connected to the high potential transformer, the potential strain may vary throughout the winding, and at some point may even be greater than at the terminal at which the voltage is applied. Under such conditions, the reading of the electrostatic voltmeter or the arcing across the spark gap affords no indication of the insulation strain. Indications, which are best learned by experience, reveal the character of the insulation under test.

The charging current of a transformer varies with its size and design. The current may be measured by means of an ammeter, placed in the low potential circuit of the testing transformer. It will increase as the voltage applied to the insulation is increased. Inability to obtain the desired potential across the insulation may be due to large electrostatic capacity, or to the inability of the high potential transformer to supply a large capacity current at the voltage desired. A breakdown in the insulation will result in a drop in voltage indicated by the electrostatic voltmeter. An excessive charging current will flow and the insulation will burn if the discharge is continued for any length of time.

Spark Gap and Arcing Distances

For any test above 10,000 volts always use a spark gap, setting it according to the sine wave curve of arcing distances.

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See Fig. 91. Use a new set of needles each time. Connect both ends of the primary winding to one terminal of the high potential transformer. Ground both ends of the secondary to the core and frame, and connect to the other terminal of the high potential transformers. Set the spark gap for the voltage to be applied, and connect in the proper electrostatic voltmeter. Be sure that everything is clear, then apply the voltage, bringing it up gradually, until the gap arcs over. Then decrease the voltage until the arcing ceases, and again bring
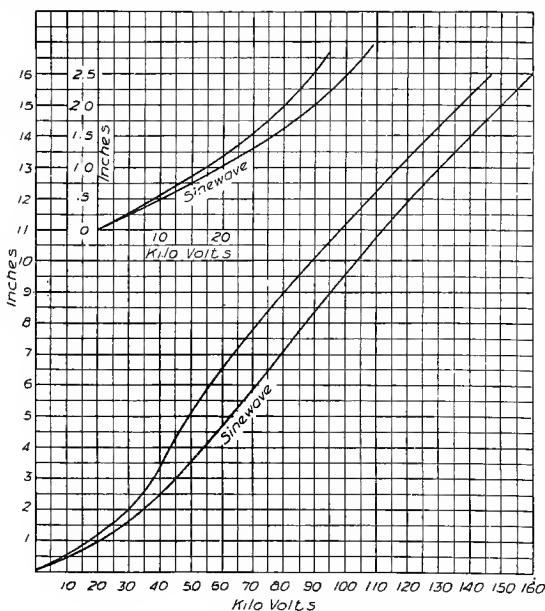
Fig. 91
CURVE OF ARC DISTANCES

it up just to the arcing point, and hold this voltage for one minute before taking it off gradually. A note of the charging current should be made on the record sheet.

All high potential tests must be taken by either the head of the test or one of his assistants.

When a transformer breaks down, the defective coil should be located by making it "smoke up." In doing this, burn only enough to show the coil. If much damage is done by smoking it may be impossible to discover the cause of the breakdown.

After all the tests have been made, remove all the shop cables, placing them on the shelves provided. Put all the fittings, such as cable couplings, doors, side plates and dampers on the transformer. See that the dampers are closed. Look over the record sheet carefully to see that nothing has been omitted. If everything is satisfactory, the floor man should be notified to put the transformer on the paint stand, unless loose laminations have to be tightened. When the loose laminations have been repaired, normal voltage at normal frequency should be applied to see that they are tight and do not buzz. If the laminations are all right, apply the double and high potential tests. If the transformer has loose laminations, omit the insulation test until repairs have been made.

Air Readings

The method at present used is to read the velocity of the air through a standard orifice by means of an air meter. Knowing the velocity and the area of the orifice the cubic feet per minute can be easily calculated. In holding the large boxes against the transformer, use a small piece of felt as packing and be careful to allow no air to escape. The size of the orifice should be noted, also the time the air meter is allowed to run. Always record the corrected reading in cubic feet per minute. The air readings are to be taken with the dampers in the same position that they were during the heat run, and at the same air pressure.

THREE-PHASE AIR-BLAST TRANSFORMERS

Special Tests

The order of tests on ABT and ABH types of transformers is the same as for the AB type. The mechanical construction of the coils is identical with that of the AB type; but as the air paths through the iron are longer than in the single-phase transformer, the air pressure required is slightly higher.

Cold Resistances

The general instructions given for the AB type apply to three-phase transformers, but since the primary circuits are opened for the heat run, the resistance of each set of coils should be measured. If the secondary coils are permanently connected in delta, measure the resistance between each set of lines, as 1–2, 2–3, and 1–3. If the secondary coils are arranged for diametrical connection, measure the resistance of each set of coils. Note on the record sheet how these readings are taken, so as to avoid confusion in measuring and recording hot resistances.

Polarity

The determination of polarity on three-phase transformers requires much care. The diagrams allow a comparison to be

made of the various standard connections. Figs. 92, 93 and 94 are three-phase connections for three single-phase transformers, and Figs. 95, 96, 97 and 98 connections of single three-phase transformers.

In determining the polarity of ABT transformers see that the primary and secondary coils are connected as shown. (See Figs. 95 and 96.) Supply direct current to primary lines No. 1 and No. 2 to give the proper deflection on the voltmeter. Now, transfer the voltmeter lines to the secondary, connecting the line that was on No. 1 primary to No. 1 secondary, and the line that was on No. 2 primary to No. 2 secondary. Break the primary current; if the polarity for this phase is correct, a positive kick will be obtained. Repeat this process for the two other phases and if they all agree with the first one, the polarity is correct. A sketch should be drawn on the record sheet, showing how the polarity test was made.

The polarity test on three-phase transformers also determines whether there will be a change of rotation of phase in transforming from one potential to the other. To determine the polarity of ABH transformers, as shown in Fig. 96, supply current to primaries 1–2 and take deflection on secondary 1–2; this should show reversed polarity. With current on 1–3 primary the deflection on 3–4 secondary should be positive. With current on primary, the deflection on 5–6 secondary should be reversed.

Besides the standard connections, there are many special connections which demand careful consideration. In determining polarity on special types, always have one of the assistant heads of the section present.

Ratio and Checking of Taps

Whenever possible, a three-phase transformer should have its ratio and taps checked on each phase separately. If this is not practicable, care must be taken to see that both primary and secondary voltages are read on the same phase. When these measurements cannot be taken single-phase, three-phase voltage must be applied. If the ratio appears to be wrong, connect both windings in delta, apply full voltage to the secondary and read the exchange current in the primary delta. This current should not exceed 6 per cent. of full load current.

Impedance

Connect the transformer according to Fig. 99 and follow the same general instructions given for the AB type. Calculate the current corresponding to the maximum primary voltage of the transformer, unless the engineering notice requires a different value. Primary current $= \dfrac{\text{capacity in watts}}{\text{line voltage} \times \sqrt{3}}$

Connect two wattmeters of the same capacity; see Fig. 99. The ratio of the potential transformers or multipliers should be the same. The algebraic sum of the readings of the wattmeters will represent the impedance loss of the transformer. The sign of the readings must be carefully noted since the

High Tension Delta

Low Tension Delta
Three Single-phase Transformers

Fig. 92

High Tension Delta

Low Tension Delta
Three-phase ABT Transformers

Fig. 95

High Tension Delta

Low Tension Diam
Three Single-phase Transformers

Fig. 93

High Tension Delta

Primary

Secondary

Low Tension Diam
Three-phase ABH Transformers

Fig. 96

High Tension Delta

Low Tension Delta
Three Single-phase Transformers

Fig. 94

High Tension Y

Low Tension Delta
Three-phase ABT Transformers

Fig. 97

High Tension Y

Low Tension Delta
Three-phase HT Transformers

Fig. 98
CONNECTIONS FOR POLARITY, THREE-PHASE

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reading of one wattmeter may be reversed. To test for this, open line No. 1; if the reading for wattmeter No. 3 is positive, the needle will drop to some value above zero. If the needle drops off the scale below zero, the reading must be recorded as negative. This process must be repeated to obtain the sign of the other meter.

An impedance curve should be taken from 50 per cent. to 125 per cent. full load.

In making the short circuit test on ABH transformers, each phase must be short circuited independently of the other. In taking readings, hold the current constant in one line from the testing table. Read the three-phase volts and the two wattmeters. Hold the voltage constant across one phase and read the current in the other phases.

Core Loss

In the core loss test, wattmeter readings are taken in the same manner as in the impedance test. The same precautions
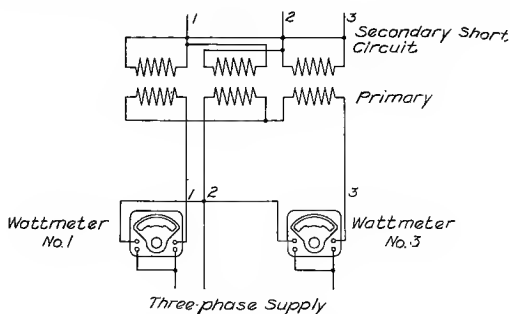
Fig. 99
CONNECTIONS FOR IMPEDANCE TEST

must be observed in regard to fastening up the primary leads so that there is no chance of danger. Take core loss curve from 50 per cent. to 125 per cent. normal voltage.

In ABH transformers, with the middle points of each phase connected together to form a neutral for a three-wire direct current system, some confusion may result as to the proper method for measuring core loss. If the neutral connection is broken (as is sometimes necessary for the heat run), the secondaries can be connected in delta, and three-phase voltage applied. This voltage is the same as the diametrical voltage, or that of each phase. If the neutral cannot be broken, the secondaries may be connected in Y, the neutral connection forming the Y point. In this case the voltage corresponding to the normal voltage of the transformer will be $\frac{\sqrt{3}}{2}$ times the diametrical voltage. It should be remembered that the middle set of coils

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should be connected so as to be reversed with respect to the other two, in order to obtain the proper magnetic flux in all parts of the core.

Hold the voltage constant and take readings as in impedance test. There will be a slight unbalancing of the magnetizing currents due to the unequal magnetic reluctances in the different parts of the core. For this reason the alternator for core loss tests must be operated at normal voltage so as to balance the three-phase voltage as nearly as possible.

Parallel Run

The parallel run checks ratio and polarity on a three-phase transformer in the same way as on a single-phase transformer.

Connect the secondary circuits of the two transformers in multiple, and the primaries as given in Fig. 100.

Connect between A and A^1, and try the fuse wire from B to B^1. If no spark is obtained, connect from B to B^1, leaving
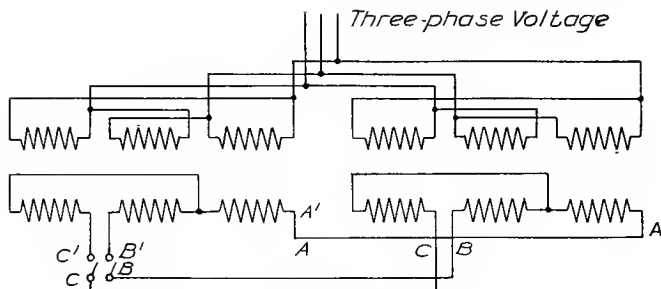
Fig. 100
CONNECTIONS FOR PARALLEL RUN, THREE-PHASE

the first connection, and try the fuse wire from C to C^1. If this is right, the parallel run test is satisfactory. The voltage must be taken off before any connections are changed.

Heat Run

The method described for three single-phase transformers is ordinarily used. If two or more transformers are to be run simultaneously, connect the transformers in multiple on the secondary side, and the primaries all in series. The same general instructions for the heating on single-phase transformers will apply—in fact, each phase of a three-phase transformer must be treated as a single-phase transformer. Use as many thermometers on one three-phase transformer as on three single-phase transformers. A higher pressure is necessary to force air through the ducts in the iron of the three-phase transformer than in the single-phase, and the damper must be carefully adjusted.

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In calculating the voltage required to supply the primary current for the heat run, the following rule may be used: If the primaries are connected in delta, multiply the impedance voltage by three. If the primaries are connected in Y, multiply the impedance voltage by $\sqrt{3}$. If overload is required, add 50 per cent. for 50 per cent. overload and 25 per cent for 25 per cent. overload. If it is impracticable to open the primary connection in order to take the heat run by applying three-phase
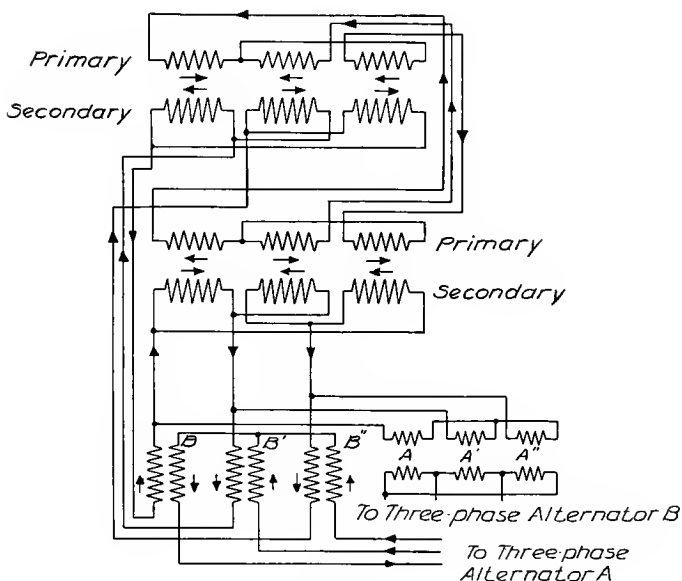
Fig. 101
CONNECTIONS FOR HEAT RUN, THREE-PHASE

voltage to the secondaries and single-phase current to the primary, the following method may be used.

Connect the transformers as shown in Fig. 101. Auxiliary transformers A, A^1, A^{11} are used to supply secondary voltage, and transformers B, B^1, B^{11}, used as series transformers, supply the impedance voltage to the secondary circuits. The voltage necessary to supply full load current is twice the impedance voltage of one transformer. The impedance voltage is the same percentage of the total voltage, irrespective of the circuit to

which it is applied. The figure shows two three-phase alternators, one supplying core loss and exciting current, and the other the copper losses. When two alternators are used they must run at nearly the same frequency, otherwise the superposition of the impedance voltage on the core loss voltage will impart a slight swing to the meter needles. Instead of the three transformers B, B^1, B^{11}, a three-phase transformer, or an induction regulator may be used. If a regulator is used, all the losses may be supplied from one alternator.

Overload Heat Run

Follow the same instructions as for single-phase transformers.

Hot Resistances

The same method as in single-phase transformers.

Double Potential Test

If any repairs or alterations are required, such as making primary delta or Y connections permanent, or connecting up the secondary neutral, the double and high potential tests should be omitted until everything is completed. If double potential cannot be obtained from a three-phase alternator on account of the high magnetizing current, the test can be made on one phase at a time. Double potential should always be followed by one and one-half potential for five minutes.

Air Readings

Air readings should be made as on AB transformers.

High Potential

The high potential should always be applied after all changes have been made, such as tightening loose iron, connecting primary delta or Y. The polarity should always be tested after the delta or Y connection has been made and should be checked with the sketch.

OIL COOLED TRANSFORMERS

The order of tests is the same as that for air blast transformers. The transformer should, if possible, be filled with oil at least four hours before starting the tests. If not, the cold resistance, polarity, ratio, checking of taps and impedance tests may be taken. Under no condition, however, should an OC, OCT or OCH type transformer for over 10,000 volts be operated at normal potential without being filled with oil, for since the coils have only one taping the insulation may break down.

Cold Resistance

If the transformer has not been filled with oil, a thermometer should be suspended inside the tank to measure as nearly as

possible the temperature of the windings. If filled with oil, record the temperature of the oil. Always use a spirit thermometer to obtain the temperatures inside the tank. As the leads are not brought out in the same manner as in the air blast type, the circuits should be carefully checked with the sketch before starting the tests.

Polarity

Take polarity in the same manner as in Air Blast Transformers. Leads of like polarity are usually brought out directly opposite each other.

Ratio and Checking of Taps

The ratio is taken and taps checked as on air blast transformers, except that it is sometimes more convenient to check taps on one transformer and then run the others in parallel with it on the taps, as well as on full winding.

Parallel Run, Core Loss and Impedance

Are taken in the same manner as the air blast, except the temperature of oil must be recorded instead of the coil temperature.

Heat Run

The methods and connections used are practically the same as for air blast transformers, except that oil cooled transformers should be started at an overload, so as to heat them up rapidly and thus shorten the run. Where practicable, they should be run with 50 per cent. excess current for two hours, and 50 per cent. excess voltage for three hours. In some cases the overload must be shortened, though occasionally a longer overload is required. When normal voltage is applied, the alternator must be operated at normal voltage.

During the heat run, a careful search should be made for oil leaks in the tank and oil gauges. If the transformer has been filled so full of oil that it is likely to overflow, draw off some oil. The leads coming from the transformer must not siphon the oil. In placing thermometers on the outside of the tank, place one at the top, about the height of the oil line. On very large transformers, place one near the bottom of the tank, always using putty. As it is not possible to obtain the temperature of the core, the oil temperature must be carefully obtained. Wherever possible, place one thermometer near the center of the transformer so as to measure the temperature of the oil as it comes from the coils. The bulb of the thermometer should be about two inches under the oil. Place one thermometer in the oil about three inches from the side of the tank.

Oil cooled transformers usually require a very long heat run, varying from 6 to 15 hours, depending on their size. The heat run should be continued until the temperature rise is less than one degree in two hours. Do not make a short circuited heat

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run on an oil cooled transformer if it can be avoided. If unavoidable, make a short circuited heat run on the coils to constant temperature; then take double potential for one minute, and one and one-half potential for five minutes and one and one-quarter potential for three hours.

Hot Resistances

Hot resistances should be measured as quickly as is consistent with accuracy, since the transformers cool rapidly.

Overload Heat Run

Follow the same general instructions as given for AB transformer.

High Potential or Insulation Test

Many oil cooled transformers are built for 50,000 to 100,000 volts and require a correspondingly high insulation test. The wiring from the high potential transformer to the transformer to be tested should be arranged so that no one can possibly make contact with it. It must be securely strung to prevent it falling on any one.

The voltage applied is controlled either by varying the field of the alternator supplying power to the low potential side of the testing transformer, or, if the power is taken from the constant potential shop circuit, by a single-phase potential regulator. The spark gap should always be used, and, if the power is supplied from a separate alternator or is controlled by a potential regulator, a high resistance, consisting of two or more glass tubes filled with clean water, should be placed in series with the spark gap. This limits the flow of current across the gap at the instant of arcing over, and prevents a sudden discharge of the transformer windings.

The transformer windings act as the plates of a condenser. If suddenly discharged, or brought to the same potential, the insulation between adjacent turns may break down. The same phenomenon occurs when the potential is suddenly applied to a transformer. To reach the interior windings, the charging current must either follow the conductors, or break down the insulation between adjacent turns. The end coils are, therefore, all strongly reinforced to prevent short circuits. The general instructions already given for high potential test on air blast transformers also apply here.

Double Potential

On transformers built to operate at 50,000 volts or over, the double potential should be the last test applied in order to discover if any breakdown has occurred between turns under the high potential test. The procedure is the same as for other type of transformers.

OIL AND WATER COOLED TRANSFORMERS

Oil and water cooled transformers are identical in construction to the oil cooled, except that instead of being placed in

corrugated tanks to radiate the heat, they are placed in smooth tanks and have a cooling coil immersed in the oil to carry away the heat generated by the losses. The cooling coils are usually made of wrought iron pipe, made up in coils of proper size by the pipe manufacturers. In special cases, however, where salt water is used for cooling, copper pipes are employed to avoid the action of the salt on the cooling coils. In most transformers these coils are placed in the upper half of the tank, but sometimes the cooling coils are made of flattened brass or copper tubing, placed between the primary and secondary coils. In large water cooled transformers with low secondary voltages, the secondary winding is made of flattened copper tubing, through which water circulates.

The tests on water cooled transformers are the same as for other types, but special instructions are necessary for handling the water. The oil in the transformer should completely cover the cooling coils. The cooling coils are tested by the plumbers to several hundred pounds per square inch, but they should also be tested by the testing department at the water pressure available. Allow water to flow through the coil until no air is left; then close the overflow, allowing the pressure to rise. Note whether there are any leaks; if not, close the inlet valve. If the pressure drops rapidly, a leak is present. If the outside plumbing and valves are tight, test the oil at the bottom of the tank for water, by drawing some off in a test tube. If water is present, it will settle to the bottom of the tube. If water is found, the cooling coil must be taken out and repaired. If the pressure, however, does not fall, leave the transformer under pressure for two hours. After all the tests are finished, the oil should be tested for water. With wrought iron pipe very little trouble is experienced.

Make all tests except the heat run according to the instructions already given on other types. In starting the heat run, run at normal rating without water, until a rise of 20° C. by resistance is reached. The oil should have a rise of about 15° C. The ingoing water should be heated up to 20° C. by using a steam heater. This is about the average temperature found in practice. The water supplied by the water main is usually much cooler than this. The water should be adjusted so as to have 10° C. rise. Temperature readings should be made every fifteen minutes, in order that the quantity of water may be properly adjusted without loss of time. As soon as the transformers have nearly reached constant temperature, the quantity of water should be noted and a record made every half hour. The water may be weighed or measured.

The amount of water required is estimated as follows: One gallon of water will require about 2650 watts to raise it 10° C. in one minute, or one gallon of water raised 10° C. in one minute will carry away the heat generated by 2650 watts loss.

For a rough estimate use one gallon of water for each 2500 watts loss. A small portion of the heat will be radiated from the outer surface of the tank. When the load is taken off the

transformers for resistance measurements, always shut off the water. Complete the tests as on other transformers, making careful inspection for oil leaks. As the leads of many of these transformers are brought out through the cover, care must be taken, in making connections, to avoid dropping tools on the porcelain bushings.

These transformers are usually made for very high voltages, and are often filled with oil that has been specially refined. The tank is exhausted of air, while the transformer is hot, and the hot oil allowed to slowly flow in from the bottom of the tank. To heat up the winding of these transformers, put one-half the full load current through the primary winding, carefully measuring the cold resistance. Take readings every half hour, calculating the rise of temperature by resistance. When a rise of 50° C. is reached, decrease the current to maintain the temperature while the tank is exhausted of air.

In water cooled transformers with secondary coils made of flattened copper tubing through which the water flows, the amount of water flowing through each section should be measured if all the sections are fed from the same water head. If each section has a regulating valve, these valves should be fully opened. Put on a low reading pressure gauge, hold the pressure constant by means of the valve in the main pipe and carefully measure the quantity of water from each section for a given time. Record the pressure and quantity per minute through each section. Never apply a pressure of over 10 pounds per square inch to a transformer of this type, as there is danger of opening the soldered joints. In taking overload heat runs, always use the same amount of water as is done for the normal load heat run.

Oil cooled and oil and water cooled transformers built for voltages above 75,000 have special high tension leads which are oil filled. These leads must be carefully filled with oil before potential is applied to the transformer, and they must be kept filled. They should be carefully watched for leaks.

TYPE K TESTING TRANSFORMERS

Type K testing transformers must be given all the tests required on other transformers. The heat run, however, is usually short, as the transformer is used only for intermittent service. In the ratio test on the Type K transformer the voltage must be applied to the high tension winding to determine the current ratio. If the voltmeter be connected to the high tension winding, the ratio will appear low on account of the drop in the high tension coil, due to the voltmeter load.

Long Commercial Tests on Transformers

Long commercial tests consist of resistances, polarity, ratio, checking of taps, impedance at normal amperes with watt-meter, core loss at $\frac{3}{4}$ normal and at normal voltage, parallel run, heat runs at normal load and insulation tests. The same

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instructions given for special tests and heat runs apply for long commercial tests, the only difference being that in the long commercial tests, the impedance curve, core loss curve and overload heat runs are omitted. Core loss is taken, however, at $\frac{3}{4}$ normal potential to act as a check on the core loss at normal voltage. At $\frac{3}{4}$ voltage the power factor is much better, and gives a more reliable wattmeter reading. The watts core loss obtained at $\frac{3}{4}$ voltage multiplied by 1.62 equals the core loss at normal voltage.

Short Commercial Tests on Transformers

Short commercial tests on transformers consist of all the tests taken in a long commercial test with the exception of the heat run. The instructions given in the long commercial test apply to the short commercial test. Oil cooled transformers should have oil left in them a sufficient time to ascertain if the oil gauges or tanks leak. Cooling coils for oil and water cooled transformers should be tested for leaks.

Efficiency Tests

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being on a non-inductive load. The power input includes the output together with the losses, which are as follows: (1) The core loss, which is determined by the core loss test at rated frequency and voltage, and (2) the I^2R loss of the primary and the secondary calculated from their resistances. As the losses in the transformer are affected by the temperature and the wave form of the e.m.f., the efficiency can be accurately specified only by reference to some definite temperature, such as 25° C., and by stating whether the e.m.f. wave is sine or otherwise. The formula for efficiency may be written:

$$\text{Per cent. efficiency} = \frac{\text{Output}}{\text{Output} + \text{core loss} + I^2R \text{ loss}}$$

Regulation Tests

In transformers the regulation is the ratio of the rise of secondary terminal voltage from full load to no load (at constant primary impressed terminal voltage) to the secondary full load voltage. Regulation may be determined by loading the transformers, and observing the rise in secondary voltage when the load is thrown off. This method is not satisfactory on account of the expense of making the test and the small difference between no load and full load secondary voltages. Much greater reliance can be placed on results calculated from separate measurements of reactance drop, resistance and magnetizing current, than on actual measurement of regulation. The following method is used by the General Electric Company:

Let IR = total resistance drop in the transformer expressed in per cent. of rated voltage.

Let IX = reactance drop similarly expressed.

Let P = proportion of energy current in load, or the power factor of the load. Non-inductive load, $P = 1$.

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Let W = wattless factor of primary current. (With non-inductive load, W = magnetizing current expressed as a decimal fraction of full load current; with inductive load, W = wattless component of load, plus magnetizing current.)

Secondary full load = 100

Secondary no load voltage = E

For non-inductive load

$$E = \sqrt{(100 + PIR + WIX)^2 + (IX)^2}$$

For inductive load

$$E = \sqrt{(100 + PIR + WIX)^2 + (PIX - WIR)^2}$$

In each of these equations, the last expression within brackets represents the drop "in quadrature."

The reactance drop expressed in per cent. $IX =$

$$\sqrt{(\text{per cent. impedance drop})^2 - (IR)^2}$$
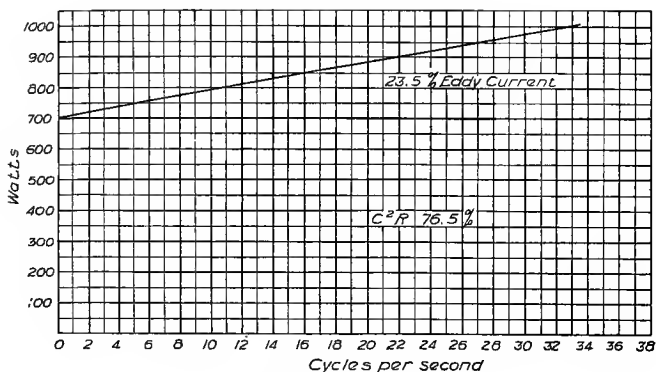
Fig. 102
SEPARATION CURVES

$$\text{The magnetizing current} = \sqrt{(\text{exciting current})^2 - \left(\frac{\text{Core loss}}{\text{voltage}}\right)^2}$$

Special Engineering Tests

The separation of the core loss from copper loss can be considered as a special test on constant potential transformers. The core loss of a transformer consists of hysteresis and eddy current losses. The hysteresis loss is that due to cylic reversals of magnetism in the core. Its value depends on the quality of the iron, and in a given transformer varies with the 1.6 power of the magnetic density. Since the density varies directly with the voltage and inversely as the frequency, the core loss increases with voltage and decreases with frequency. Eddy current loss is due to electric currents flowing in the iron. It varies with

the conductivity of the iron, the thickness of the laminations and the square of the frequency.

The method for separating the losses is as follows: Since the hysteresis loss varies directly with the frequency and the eddy current loss as the square of the frequency, by maintaining a given density in the core and varying the frequency, data may be obtained from which a separation curve may be plotted. The voltage to be applied varies directly with the frequency at which it is applied, thus 100 volts at 60 cycles becomes 200 volts at 120 cycles. Plotting watts per cycle as ordinates and cycles as abscissæ, the curves shown in Fig. 102 are obtained. At least four points should be taken to determine the curve. By comparing the losses at normal frequency and density, the quality of the iron as well as that of the insulation between laminations can be deduced.

The eddy current loss in the copper conductors of a transformer may be separated from the ohmic loss in the following manner: The ohmic loss is independent of frequency, while the eddy current loss varies with the square of frequency. Hold the current constant and take readings of watts, volts and speed. Plot watts loss as ordinates and cycles as abscissæ, and project the curve back to the zero line. At zero frequency, the total loss will represent the true ohmic loss or I^2R. See Fig. 103.

In very exceptional cases, short circuit tests are taken on transformers to determine their behavior in case they are accidentally short circuited in service. This test is obtained by connecting one winding of the transformer to the power source, which should be four or five times the capacity of the transformer, and short circuiting the other windings. The tendency of the ends of coils to flare out due to the excessive magnetic repulsion is the important point in this test. The test should be short, as the current is from 15 to 30 times normal.

SERIES TRANSFORMERS

Series transformers designed to supply current for operating meters and relays are usually known as Type S. They are generally tested in groups of ten to twenty at a time. The tests made are cold resistance on the secondary winding of one out of every five; each transformer should have polarity, ratio, heat run and insulation tests. To test the insulation between layers, they are run for one minute at full load primary current with the secondary open. The primary and secondary windings must be carefully distinguished. In series transformers the winding that is to be connected in series with the circuit is called the primary, and the primary leads are nearly always brought out through much larger bushings than the secondary leads.

Cold Resistance

When several transformers are tested at the same time, a measurement of cold resistance on the secondaries need only be taken on about one-fifth of the transformers in the group. The primary resistance is too low to be measured accurately, and this test is usually omitted. The same precautions must be observed on these transformers as on a large transformer.

Polarity

Polarity should be carefully taken. If the polarity is not correct, trouble will be experienced in making connections for polyphase meter circuits.
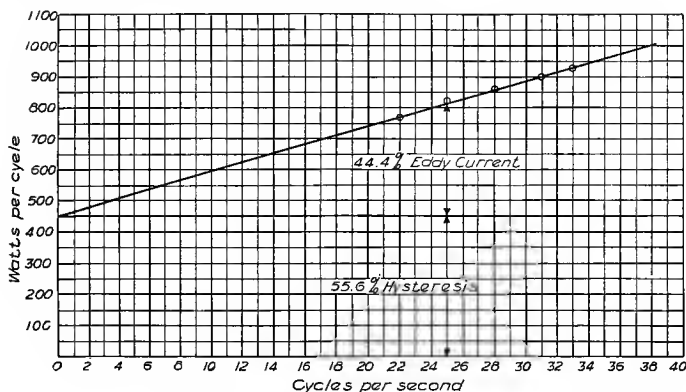
Fig. 103
SEPARATION CURVE

Ratio

Instead of actually determining the ratio, the transformers are checked with a standard. The one selected as standard must be sent to the Standardizing Laboratory to be carefully checked for ratio at proper load and frequency. Having selected one of the group as a standard, connect the primaries of all the transformers in series. Short circuit all the secondaries as shown in Fig. 104, connect the ammeter to the secondaries of the standard and check the transformer. This connection must be made of lamp cord, or other suitable wire, and sufficiently long to allow the ammeter to be at least ten feet from the primary circuit, to avoid stray field effects. Correct the reading for the ammeter connected to the standard by means of a check ammeter; bring the current up to this reading and note the reading of the check ammeter. Now transfer the ammeter on

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the standard to another transformer and bring the current up to the reading previously noted or the check ammeter. When correct, read the ammeter on the transformer in test; if this reading agrees with the reading when the ammeter was on the standard the ratio is correct. Proceed in this manner until all the transformers have been checked with the standard.

New check readings are often necessary, due to unequal heating of meters and lines. Record the number of the standard transformer and readings on the standard, and the transformer corresponding with it. Ratios should check within one per cent. Keep all secondaries short circuited except those to which the meter is connected.. A few transformers of this type are built with two sets of windings. Such transformers should be tested as if they were two separate transformers.
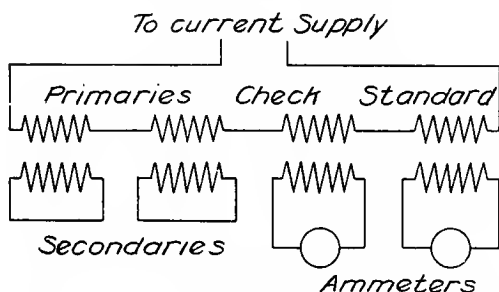
Fig. 104
CONNECTIONS FOR RATIO IN SERIES TRANSFORMER

Heat Run

On a new design of transformer a heat run should be taken at normal primary current, with the secondary short circuited until constant temperature is reached, taking temperature rise by resistance hourly on one transformer out of every five, and thermometer temperatures on each one. When constant temperatures are reached, the transformer should run for two hours at the thirty minute load, which will be found stamped on the name plate. On transformers that are duplicates of some previously built, a two hour heat run at the thirty minute load is sufficient. Measure hot resistances on one out of five and take thermometer temperatures on all. They should then be run for one minute at the thirty minute load with the secondary open to test the insulation between turns and between layers. This corresponds to the double potential test on other transformers.

The high potential test may be taken on several transformers at the same tme. See that all secondaries and cases are properly connected together. Series transformers used in connection

with potential regulators have the same characteristics as constant potential transformers and are tested as such.

POTENTIAL REGULATORS

Potential Regulators are built in three distinct types: MR regulators, induction regulators, and BR regulators. There are also several modifications of these types, each of which requires special tests.

Tests

Few MR regulators are now built, the design having been superseded. The tests are similar to those given to the I.R.S.

Complete tests on regulators consist of special tests and normal and overload heat runs, and insulation tests.

Special tests consist of core loss curve, impedance curve with wattmeters, boost and lower curves.

General tests consist of boost and lower at no load, core loss at normal voltage and impedance at normal current with wattmeters. Normal load heat run consists in operating the regulator until it shows constant temperature at normal volts and amperes.

Overload heat run consists in operating the regulator until it has reached normal load temperature, and then applying the required overload for the specified time.

Commercial tests consist of general tests and a heat run at greater than normal volts and amperes for a short time, to show if the regulator is free from electrical and manufacturing defects.

INDUCTION REGULATORS

The IRS, or single-phase induction regulator may be cooled by air blast, it may be placed in a ribbed tank and be oil cooled, or it may be oil and water cooled. Regulators of this type are built for use with electric furnaces, and for the control of single-phase lighting feeders. In the single-phase induction regulator, the primary winding is placed in slots on the movable core or armature. The secondary winding is placed in slots in the stationary core. The regulator may be wound as two-pole, four-pole, six-pole, or with any even number of poles.

The voltage induced in the secondary winding depends upon the relative position of primary to secondary windings, the primary being in shunt and the secondary in series with the circuit to be controlled, the voltage of the circuit being increased or decreased accordingly. Single-phase, as well as polyphase regulators, have a distributed winding for both primary and secondary, but the maximum pole face which can be covered by an active winding in a single-phase regulator so as to produce the best results, is approximately 60 per cent. In the neutral position of the regulator, the secondary winding therefore encloses an area on the primary core not enclosed by an active primary winding, and the impedance would be extremely high

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if no winding were provided. The slots of the primary not used for an active winding are, therefore, filled with a short circuited winding so that, in the neutral position of the regulator, the current forced through the secondary induces a current through the short circuited winding, and which reduces the impedance.

The tests required are cold resistances, "boost" and "lower," core loss, impedance, heat run and insulation. Cold resistance is measured as on transformers. The "boost" and "lower" test is made at the full potential of the regulator. It therefore requires care, as the magnetic leakage is greater at normal potential than at a lower potential. Connections for this test are shown in Fig. 105.

The volts primary and volts secondary should be read on the same voltmeter by using a double-throw switch. Throw the switch to the primary and bring the voltage up to the correct reading on the check voltmeter B. Throw the switch to the secondary, bring up the voltage to that noted on the check voltmeter and read the secondary voltage. Take these readings
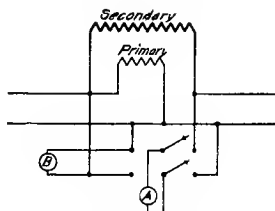
Fig. 105
CONNECTIONS FOR BOOST AND LOWER ON REGULATOR

at maximum "boost," neutral and maximum lower positions. The turns of the handwheel from maximum "boost" to neutral and from neutral to maximum lower should be counted and recorded on the record sheet. The induced secondary voltage must be added to the primary voltage at maximum "boost" and subtracted from it at maximum lower.

Check the index plate on the handwheel to see if it is correct; that is, see that the voltage is "boosted" when the index is turned in the direction indicated by "Raise." In addition to the boost and lower test, the induced voltage of the secondary coil should be taken at maximum boost and maximum lower with full voltage on the primary coil. This is to act as a check on the boost and lower test. In taking boost and lower curve, great care should be taken in obtaining points near the end of the segment. About twenty points in all should be taken from maximum boost to maximum lower, holding the primary voltage constant and reading secondary volts at different positions of the armature.

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Impedance

Impedance is always measured on the secondary winding, as it is impossible to force full load current through the primary winding at the neutral position. In taking the curve, supply full load current to the secondary, the primary being short circuited through an ammeter, taking readings of watts secondary, volts secondary, and amperes primary at various positions of the armature. At maximum boost position take an impedance curve from 50 per cent. full load to 150 per cent. full load. The full load point of impedance for general tests should be taken at the maximum boost position, unless other instructions are given. Always record the temperature.

Core Loss

On the IRS type of regulator with the permanent short circuit on the armature, the core loss must be taken from the primary winding. The power factor will be low due to the air gap, hence considerable care must be taken in making the test. Take a core loss curve at maximum boost from 50 to 150 per cent. normal potential, also hold normal potential and take readings at various positions of the armature, reading amperes and watts primary. In taking single point core losses for general tests, the armature should be in the maximum boost position.

Normal Load Heat Run

The heat tests are usually made by pumping one regulator back on another; they may, however, be loaded on water boxes, or pumped back against a suitable bank of transformers. The permanent short circuit on the armature introduces complications in the heat run, since at any position except maximum boost and maximum lower, the short circuited coil carries some current if the impedance voltage is supplied from the secondary.

The amount of current in the short circuited coil depends upon the position of the armature. Hence, in taking a heat run, connect the primaries of the regulators in multiple and apply full primary voltage at the proper frequency. Ammeters should be placed in each primary circuit. Connect the secondaries in multiple through an ammeter. Place the armature of one regulator in the maximum boost position and shift the other until full load primary and secondary is obtained on the first regulator. The other regulator will have full load secondary current and a partial load primary, the short circuited winding on the armature accounting for the current not appearing in the primary. Both regulators would generally pass on the results of these heat runs. When special guarantees are required, however, the heat run should be finished on the first regulator, and then the second regulator should be run with the armature in the maximum boost position.

Overload heat runs are usually taken as a continuation of the normal load heat run. To shorten the heat run, the regulator, if air blast, may be operated a short while without air; if oil

cooled, it may be operated at an overload. If oil and water cooled, it may be operated for a time without water. Careful inspection should be made for oil leaks and other mechanical defects.

Hot resistances should be taken in the same manner as in transformers.

The insulation tests consist of double and high potential and are taken in the usual way. The secondary coil, although only a low voltage is induced in it, is in series with the circuit to be controlled. It should, therefore, have the same potential as the primary winding.

Operating Motor Tests

If the regulator is provided with an operating motor and limiting switch, they should be tested during the early part of the heat run so as to save rewiring after the heat run is finished. The motor and limiting switch should be connected up according to the proper sketch, and readings at normal potential and frequency should be taken of the current with the motor disconnected from the shaft, with the motor operating the regulator in both directions at no load, and at full load in both directions. When the regulator is under full load, the motor should operate it from one extreme position to the other. To keep load on the regulators while this is being done, the handwheel of one regulator need only be turned. The time required to travel from one end of the segment to the other should be taken and recorded. The limit switch should be adjusted so as to work properly.

POLYPHASE INDUCTION REGULATORS

Induction regulators of the IRQ, IRT and IRH types are used principally with rotary converters, but are well adapted to control polyphase transmission circuits. As in the IRS type, they may be either air blast, oil cooled or oil and water cooled. The primary winding is connected in shunt and the secondary in series with the circuit. In the polyphase induction regulator, the voltage induced in each phase of the secondary is constant, but by varying the relative positions of the primary and secondary, the effective voltage of any phase of the secondary on its circuit is varied from maximum boost to zero and to maximum lower.

Referring to Fig. 106 which represents graphically the voltage of the three phases of a three-phase or IRT regulator, AAA = the line voltage or the e.m.f. impressed on the primary. This is shown by the large circle. Let BA, BA and BA equal e.m.f. generated in the secondary coils, and constant with the impressed e.m.f. This is shown by the three small circles on the circumference of the large circle. BBB shows e.m.f. induced in secondary coils directly in phase with the primary impressed e.m.f. This is the position of maximum boost. Positions CCC represent the neutral position, and DDD the maximum lower position. EEE represents a position between neutral and maximum lower.

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By changing the position of the armature with respect to the field the secondary voltage may be made to assume any phase relation with respect to the primary e.m.f.; it can be in series with it or directly opposed to it. This movement of the armature is obtained by means of a segment on the shaft which meshes with a worm on the small operating shaft. The regulator may be arranged for hand operation only, or can be motor operated. Either a direct current or an induction motor may be used. The motor is controlled by a small double-pole double-throw switch, on the switchboard, to allow the voltage to be raised or lowered as desired.

To stop the regulator on reaching the limits of regulation when moving in either direction, a limiting switch is provided, which opens automatically. If properly connected, this automatic cut off, however, does not interfere with movement in
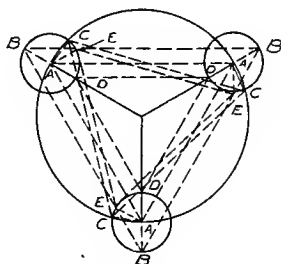
Fig. 106
REGULATOR DIAGRAM—THREE-PHASE

the opposite direction, which can be obtained by the double-pole double-throw switch.

The winding of the primary and secondary is similar to that of a Form M Induction motor. The primary is placed on the movable core. For a three-phase or six-phase regulator it may be Y or delta connected; for an IRH six-phase diametrically connected regulator, the primary is connected diametrically. The secondary or stationary winding is placed on the stationary core, and is an open winding, each section or phase being connected in series with the corresponding phase of the line of which the voltage is to be controlled.

The tests required are cold resistance, "boost" and lower, core loss, impedance, heat run, hot resistance, double potential for one minute, one and one-half potential for five minutes, and high potential test. If the regulator is motor operated, the motor should be tested. This should be done during the heat run to save rewiring. Air readings should be taken on the air blast regulators.

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Cold Resistance

Before starting the tests, carefully check all circuits. If the secondary coils have two studs on each end per phase, test to see if the studs are connected in multiple or if each secondary consists of two separate coils which are connected in multiple by the cable lugs. If the regulator is six-phase IRH, test to see if there are two primary circuits. On six-phase IRH's, Fig. 107, primaries 1–3–5 should be one set, and 2–4–6 the other. On an IRH regulator, 1 and 4, 2 and 5, and 3 and 6 should give proper circuits. If each secondary circuit has two coils that are connected in multiple, by the cable lugs, the top stud
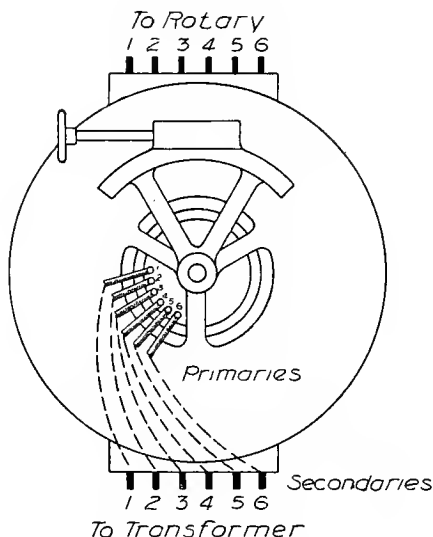
Fig. 107
SIX-PHASE REGULATOR

on one side is generally connected to the bottom stud on the opposite side, and *vice versa.*

Measure the resistance as on a transformer. In recording the secondary resistances, a note should be made of the place on which the drop lines were placed. Take the resistance of each secondary coil, and make a sketch showing the numbers that have been given to the various circuits. Record the temperature of each coil, or of the oil.

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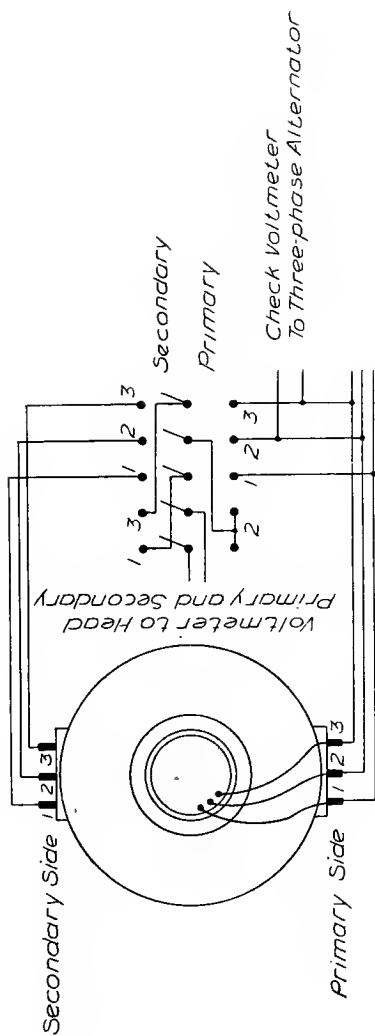
Fig. 108

CONNECTIONS FOR BOOST AND LOWER THREE-PHASE

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"Boost" and "Lower"

The "boost" and "lower" test is made at normal voltage and frequency. On three-phase regulators, apply a balanced three-phase voltage to the primary, using a three-pole double-throw switch to transfer the voltmeter from the primary to the secondary. (Primary and secondary here refer to the voltage to be controlled, and the controlled voltage respectively.) The Regulator must be connected as in service, the primaries being in shunt, and the secondaries in series, with the circuit to be controlled. A voltmeter should be placed across one phase for a check. Fig. 108 shows the proper connections for a three-phase "boost" and "lower" test. Adjust for the proper voltage on the voltmeter that is used on both primary and secondary, and note the readings on the check voltmeter. Throw the three-pole switch to the secondary and read the voltage on the corresponding phase of the secondary. Do this for all three phases at maximum "boost," neutral and maximum "lower." A curve of about 20 points should be taken on one phase.

The voltage balance should be taken at maximum "boost," neutral and maximum "lower." Count the number of turns of the handwheel from maximum "boost" to neutral and from neutral to maximum "lower" and record on the record sheet, to check the mechanical construction. Maximum "boost" and "lower" do not always come at extreme ends of segment. The voltage readings should be taken at every turn of the handwheel for a few turns from each end, to locate the maximum positions. Check the index on the handwheel to see that it indicates the proper direction for "boost" and "lower." If the proper connections do not give the correct "boost," and "lower," the matter should be reported at once, as correcting crossed leads on polyphase regulators requires a great deal of care. The induced voltage in the secondary coil should be measured and recorded, as well as the "boost" and "lower."

In some types of IRH regulators, the terminals of the secondary coils are crossed instead of being directly opposite each other. See Fig. 109. In such cases take care to properly record the "boost" and "lower" and make a clear sketch showing the arrangement of the secondary terminals. "Boost" and "lower" may be taken on six-phase IRH regulators, as though they consisted of two separate regulators; that is, the test may be made on 1–3–5 and then on 2–4–6. Six-phase voltage must, however, be applied and a set of six-phase "boost" or "lower" readings must be taken to determine if the regulator is satisfactory.

Fig. 110 gives the method of obtaining six-phase voltage which should be tested before proceeding. With the connections shown in Fig. 110, the voltages corresponding to the six sides of a hexagon can be obtained by reading 1–2, 2–3, 3–4, 4–5, 5–6 and 6–1. Unless six-phase voltage is used, don't try to make a "boost" or "lower" test. The induced secondary voltage of each secondary coil should be recorded.

The "boost" and "lower" test on IRH, or diametrically connected regulators must be made by applying a six-phase

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diametrically connected voltage, tested as previously described. The transformer connections are shown in Fig. 111. A neutral point is made so that six-phase voltage may be read. In taking "boost" and "lower," read the diametrical voltage, carefully checking the six-phase "boost" or "lower" and recording the same as the diametrical "boost" or lower." Measure and record the induced voltage across each secondary coil.

Core Loss

For low potential three-phase regulators, core loss is measured in the usual way by applying normal potential to the primary winding. For regulators of which the primary voltage exceeds 1100 volts, it should be taken from the secondary winding. The voltage required is specified by the engineering department.

For six-phase two-circuit primary regulators, one set of core loss readings on lines 1–3–5 and another on 2–4–6 should
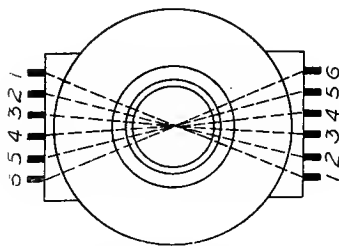
Fig. 109
REGULATOR—SIX-PHASE

be taken. Either set should give the correct core loss. For six-phase diametrically connected regulators, core loss may be determined by applying six-phase voltage and reading the core loss in each phase and taking the sum of these losses. It may also be taken by connecting the primaries in delta, reversing one primary coil to maintain the proper distribution of magnetic flux. Apply the rated primary voltage, and determine the core loss by the two-wattmeter method. Another method of determining core loss is by connecting the primaries in Y and applying 1.73 times the rated potential. One coil must be reversed for the Y connection, as is done for the delta connection.

In a core loss test, record the voltage, exciting current and wattmeter readings. The test must be made at the proper frequency and the generator supplying the loss must operate at normal voltage. The magnetizing current will vary from 20 to 40 per cent., depending upon the air gap. A curve should

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be taken beginning at 50 per cent. normal voltage and increasing to at least 125 per cent. normal voltage. Whenever possible, neither potential nor current transformers should be used with the wattmeter, in consequence of the very low power factor. During the core loss tests the armature should be in the maximum "boost" position. A curve should also be taken by holding normal voltage and varying the position of the armature.

Impedance

Impedance is usually measured by short circuiting the secondary and applying sufficient voltage to the primary winding to give full load current. The impedance voltage varies
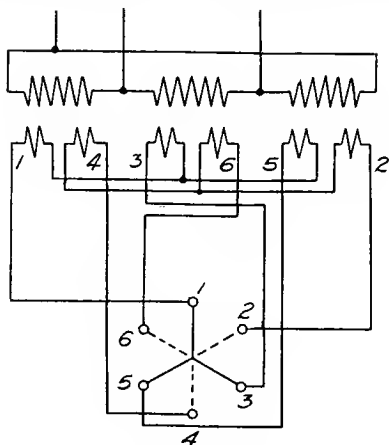
Fig. 110

METHOD OF CONNECTING FOR SIX-PHASE VOLTAGE

from 15 to 20 per cent. Impedance should be taken on three-phase regulators by using three-phase voltage, and on six-phase regulators by using six-phase voltage. Wattmeter readings are not required, as the efficiency is calculated, using the I^2R losses as computed from the resistances. When calculating the full load primary current for this test, assume that the regulator operates at an apparent efficiency of 80 per cent. (a power factor of .8).

In special cases, impedance may be taken from the secondary side. In such cases, connect the secondaries in Y, and apply rated current. An ammeter should be placed in one phase of the short circuited primary. If the primary is permanently connected to the secondary inside the machine, each secondary

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coil must be short circuited on itself. On all other types, the secondary is short circuited by connecting all the secondary terminals on either side with a copper bar.

A curve should be taken from 50 to 150 per cent. full load, with the armature in the maximum "boost" position. A curve should also be obtained by holding full load current and varying the position of the armature. This curve should be very carefully taken over one-half of the segment, to obtain the maximum impedance.

Heat Run

Whenever possible, heat runs should be made with full load, either by pumping one regulator back on another, or by pumping back against a bank of transformers. The heat run
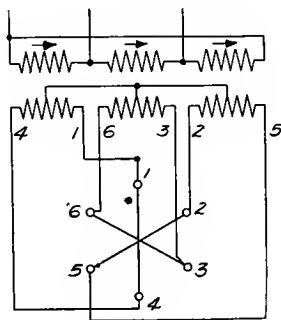
Fig. 111
CONNECTIONS FOR SIX-PHASE BOOST AND LOWER

on two regulators of the same size and type is made by connecting the primaries in multiple through a dynamometer board. One end of the secondary coil of the regulator is connected to the end of the secondary coil of the other by short circuiting bars. The other ends of the secondary coils of one regulator must be in multiple with corresponding coils of the other regulator. Normal voltage of the proper phase and frequency is applied to the primaries of the two regulators. The hand-wheel of one regulator must be turned so as to cause sufficient phase displacement of the secondary voltages of the two regulators for full load current in the secondary winding.

In pumping back against a bank of transformers, the same general method is used. The ratio of transformation of the transformers should be about equal to that of the regulator. The same temperature readings should be taken as on a transformer using a similar method of cooling. Carefully observe

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if there is any noise while under load. If humming is noticed during the core loss test, the cable lugs connecting the two secondary circuits in multiple should be removed to see if the humming is caused by exchange current.
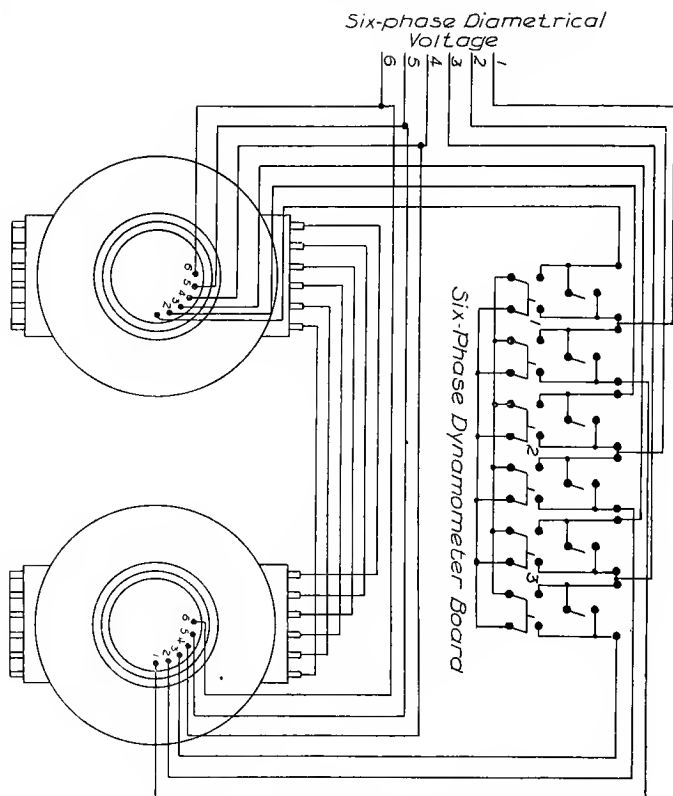
Fig. 112
CONNECTIONS FOR HEAT RUN ON SIX-PHASE REGULATORS

Fig. 112 shows the connection for the heat run on two IRH regulators. See instructions under Operating Motor Tests.

When the heat run is finished, measure all hot resistances and finish the tests as on transformers. In taking high potential test between the secondary windings, a very high charging

Feeder Regulator Connections.
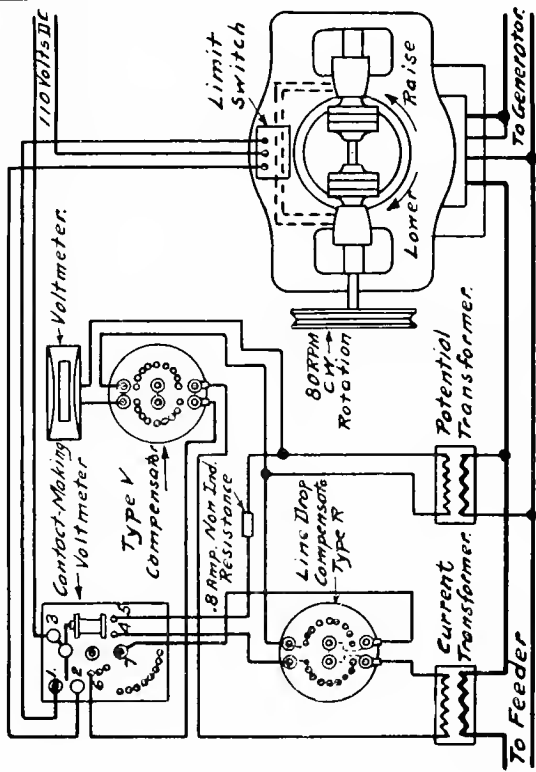
current is necessary on account of the large electrostatic capacity. The damper of the air blast regulator should be inspected for proper operation. Oil cooled regulators should be inspected for leaks. A pressure test should be made on the cooling coils of water cooled regulators. IRQ regulators are seldom built. They must have the same tests as the IRT types.

BR REGULATORS

Modern central stations employ alternating current generators of large capacity, each generator usually supplying two or more districts through independent feeders. One feeder may serve a business district, while another from the same generator may feed a residential district. As the compounding required on any of the feeders depends on the amount of load carried by the feeder, and as the load peak occurs at different times in different feeders, a device to regulate the feeder voltages independently is necessary.

Type MR regulators cannot be built in sufficient capacities to regulate all circuits properly. Type IRS may be used, but the automatic BR feeder regulator has been expressly designed for this work. Fig. 113 shows the circuits.

The automatic BR feeder regulator can change the line voltage quicker and with a smaller power consumption than other automatic types. The only moving part is a small and light switch arm. The friction of a number of small switch contacts constitutes the only turning resistance.

The moving part of the switch carries a series of fingers, the majority of which are always in contact. See Fig. 114. Each finger is connected to a corresponding stationary collector ring by a brush, and the collector ring is connected to the line through a preventive resistance. The resistances connecting the fingers to the line prevent excessive exchange currents as the fingers pass from contact to contact, and vary the line voltage uniformly. The regulator transformer is oil cooled.

The tests required are: resistances, tap voltages or ratio, core loss, impedance, heat run, insulation tests and checking the clutch coil and limit switch circuits.

Cold Resistance

Measure the cold resistance of the primary winding, each half of the secondary and of the iron grid resistances. To obtain the resistance of each half of the secondary winding, turn the switch to the extreme position and take readings. Show the switch position by a sketch. Then throw the switch into the other extreme position, and measure the other half of the secondary winding.

Tap Voltage or Ratio

When the switch contacts are accessible, full voltage should be applied to the primary winding, reading the voltage between the steps on the switch. This test will show any wrong switch connections immediately. Correct connection can also be

checked by a polarity test on each step. If properly connected all steps have the same polarity; that is, the voltmeter deflections are all in the same direction.

If the contacts of the switch are inaccessible, the step voltages may be taken as follows: Throw the switch to the neutral position, apply full voltage to the primary and connect the
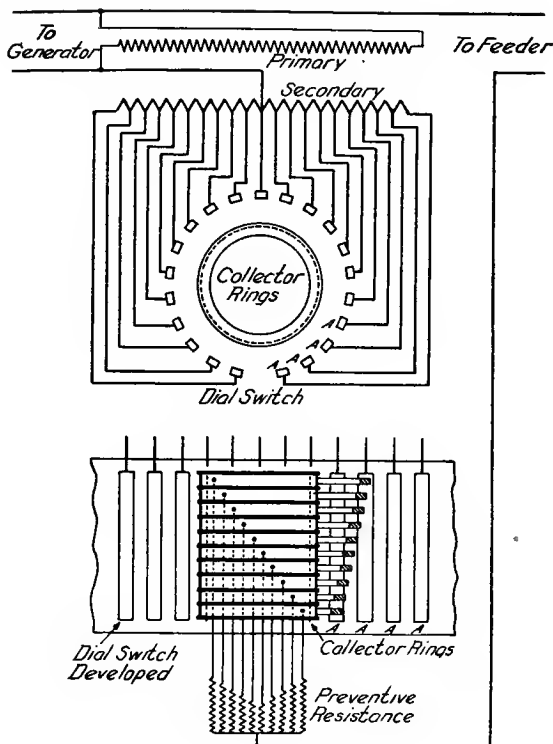
Fig. 114
BR REGULATOR

voltmeter across the secondary. When the switch is in the neutral position, no secondary voltage will be obtained. Move the switch one step and read the secondary voltage. Move the switch to the next step. The reading obtained should correspond to two steps in series. Continue until the switch has reached the extreme position. Bring the switch back to

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the neutral, then test the steps on the other half. If the sections of the secondary winding are properly connected to the dial, the voltmeter readings should increase in equal increments.

Core Loss

Core loss may be determined from the primary, but is more satisfactorily determined from the secondary. Throw the switch to the extreme position and apply the rated "boost" or "lower" voltage, reading watts input and exciting current at the proper frequency. The per cent. loss and exciting current will be about the same as for a Type H transformer of the same kw. capacity. Throw the switch into the other extreme position, and repeat the test.

Impedance

Supply current to the primary, with the secondary and iron grid short circuited through an ammeter, the switch being in one extreme position. Increase the primary current until full rated current is obtained on the short circuited secondary and read amperes, watts and volts primary at the proper frequency. Throw the switch into the other extreme position, and repeat. Impedance must be taken with the switch in both extreme positions, as in either position only one-half of the secondary winding is short circuited.

Heat Run

If two regulators are in test at the same time, they may be "pumped back" on each other. If only one is in test, it may be pumped back on a suitably arranged bank of transformers, or be loaded on a water box. In the latter case apply voltage to the primary, connecting the secondary to a water box, adjusting until full load secondary current is obtained. The switch must be in one of the extreme positions. Take and record the temperature, also record the temperature of the iron grid resistance.

Start the test at overload so as to shorten the length of the heat run. Finish as if testing on a transformer. Throw the switch in the other extreme position, and run at 50 per cent. overload current for one hour to test the other half of the secondary.

Insulation Tests

Apply double potential for one minute and one and one-half potential for five minutes. High potential tests are the same as on a transformer. If the primary is connected to the secondary inside the tank it is not possible to test between the primary and secondary windings. If the clutch coils, relay coil, and relay voltmeter operate on a circuit of 125 volts or less, test with 500 volts between the winding and frame. The tank and oil gauges should be inspected for leaks.

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STARTING COMPENSATORS

Compensators for starting Form K induction motors, synchronous motors, and rotary converters are built for voltages from 110 to 13,200 volts. The switching mechanisms constitute the chief difference between the various forms. The Form F has a double-throw oil switch. It is so connected that when the motor is thrown on the line, the fuses are in circuit. Figs. 115 and 116 show the wiring for Form F, quarter-phase and three-phase compensators. The tests required are ratio,
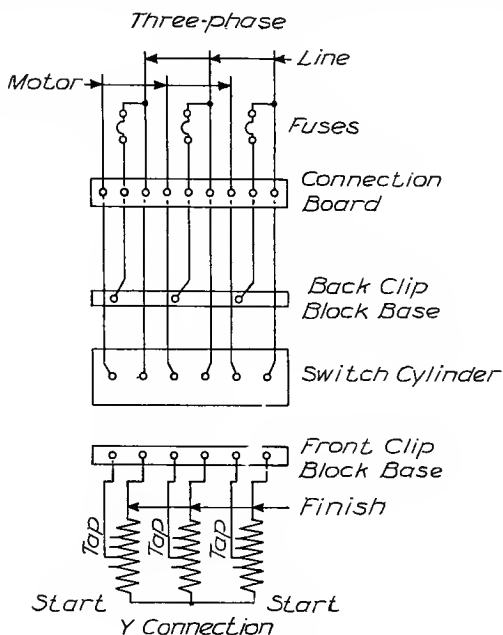
Fig. 115
COMPENSATOR—THREE-PHASE

magnetizing current, heat runs when required, double potential and high potential.

Complete tests on compensators consist of commercial tests, heat runs, impedance, and insulation tests. Commercial tests consist of ratio taps, exciting current at normal voltage and insulation tests. Insulation tests consist in applying high potential between windings and ground for one minute, operating the compensator at double potential for one minute, and also at 50 per cent. above normal potential for five minutes.

Ratio

Connect the line leads to the terminals on the side of the testing stand. These terminals are connected in multiple by bus bars at the back of the terminal board. Apply about 100 volts to the lines; throw the switch on the compensator in test to "starting" position, leaving all others in the "off" position. On the three-phase compensator read the voltages between the taps; the lowest voltage tap is next to the core. Standard compensators for motors up to and including 15 h.p. have
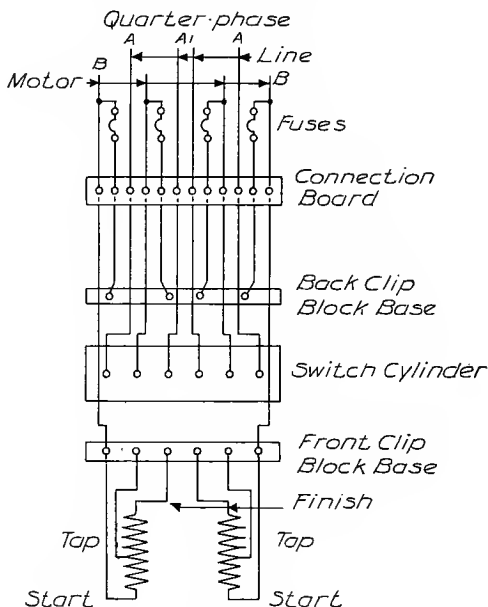
Fig. 116
COMPENSATOR—QUARTER-PHASE

40, 60 and 80 per cent. taps; those for motors above 15 h.p. have 40, 58, 70 and 85 per cent. taps. The ratios obtained should agree to within 3 per cent. of the above.

In determining ratios see that both the primary and secondary meters are on the same phase. In checking the ratio of Form F quarter-phase compensators, apply 100 volts to the lines A and A (see Fig. 116) and read the voltage on the taps between the motor lead B and the taps. These compensators are tested single-phase.

Magnetizing Current

Magnetizing current is measured at normal primary voltage, the frequency being held constant. The alternator used should operate at normal voltage. On 60 cycle compensators, the magnetizing current should not exceed 20 per cent.; on 40 cycle compensators, it should not exceed 25 per cent., and on 25 cycle compensators it should not exceed 30 per cent. of the full load current of the motor, assuming the latter to operate at 80 per cent. apparent efficiency.

On compensators covered by engineering notices, and on those not standard, the magnetizing current should be measured at 20 per cent. above the normal potential as well as at normal. In making this test, hold the volts constant across one phase, and read the current in all three legs, then hold the current constant in one leg and read the three-phase voltage. Instead of holding the current in one leg, two voltmeters may be used, using one to hold the volts constant and the other to read the three-phase volts. As a high magnetic density obtains in the core, see that the voltage and frequency are correct, since a slight change in either will change the magnetizing current considerably. Quarter-phase compensators are tested as if they were single-phase.

Heat Run

Short circuit the motor leads and apply sufficient voltage to the line leads to force the required current for one minute through the coils. The value of the current required is given in the card file. Thirty minutes must elapse between successive heat runs on the same compensator. Place a thermometer on the coils to obtain the temperature. After each heat run the tap leads must be changed to the next tap.

On very large compensators it is often necessary to wait several hours between heat runs. Otherwise the compensator runs hot and smokes. The heat run cannot always be taken on all legs at the same time on account of insufficient power. In such cases, bare the Y connection, short circuiting the tap to the Y.

On compensators not standard, or those covered by special engineering notice, the impedance volts must be measured. See that frequency is correct for this test. When the heat runs have been finished, inspect the oil boxes for leaks. If they are tight, empty the oil out and turn them upside down to drain. Connect the top leads on the first tap, replace the oil boxes, tape and insulate all the connections and replace the covers. All cast iron oil boxes are tested for leaks by filling with oil for 10 hours. Pressed steel boxes are not tested and therefore need not be removed from the compensator.

Insulation Test

The double potential must always be applied after the compensator has been completely assembled and the taps insulated with tape. Double voltage is applied to the line

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terminals for one minute, followed by $1\frac{1}{2}$ potential for 5 minutes, the frequency being high in order to keep the magnetizing current below the normal current of the compensator.

If the compensator is designed for high voltage, double potential may be applied for one minute on the taps. The high potential test is made in the usual way; all leads must be connected together. Compensators up to and including 550 volts are tested with 2500 volts.

ROTARY CONVERTER REACTANCES

Reactances

Reactances are generally used in compounding rotary converters. They are placed between the secondary of the step-down transformer and the collector rings of the rotary.

The ratio of conversion of rotary converters, except those of the split pole type, is practically constant for all field strengths. Therefore, to increase the continuous current voltage, the alternating current voltage must also be increased. In large systems, with a number of substations fed from the same generating station, any given substation voltage must be varied independently of the others. Several methods are possible; for lighting systems an induction regulator is often employed. The step-down transformers may be provided with a dial switch, to vary the ratio of transformation. These devices do not operate automatically, whereas the compounding of a rotary converter is automatic. The excitation of the shunt field is adjusted at no load to a value which causes the machine to take a small lagging current. This lagging current flowing in the reactive coil reduces the voltage at the collector rings below that at the transformer terminals. As the rotary takes load the current through the series field first reduces the wattless current through the reactive coils and at higher loads forces a leading wattless current through the coils. When the current becomes leading, the voltage at the collector rings is higher than at the terminals of the transformers.

Rotaries may be made to over compound; that is, increase in continuous current voltage as the load increases.

Reactive coils are often placed in multiple with long distance high voltage transmission lines to compensate for capacity. Reactive coils are also used as dimmers.

Complete tests on reactive coils for rotaries consist of measurements of resistance, reactive drop, and heat runs at normal and overload, polarity and insulation tests. Reactive drop is usually taken during the heat run. Reactive coils have the same heating guarantees as the transformers with which they operate.

Commercial tests consist of resistance measurement, reactive drop, polarity, short heat run at overload, insulation.

For the heat run, connect the coils in Y and supply full current at proper frequency. See that the meters are protected from stray fields. The transformer cables should be kept

close together, to prevent high impedance and unbalancing. Heat runs on air blast reactances should be started without air at normal load for about thirty minutes before the air blast is put on. Oil cooled reactances should be started at overload to shorten the heat run as much as possible.

In making heat runs on reactances designed for six-phase circuits, connect the coils in series and make the heat run three-phase. Reactive coils cannot be tested by the motor-generator method, hence the test must be run from an alternator capable of supplying full kilo-volt-amperes. If an alternator of sufficient capacity is not available, use two in multiple. They can be run as generators, but after the alternators have been synchronized it is better to pull the breaker of the driving motor of one of them. By proper adjustment of the field current, the one running light will operate as a rotary condenser, by overexciting it.

In measuring reactive drop, take the volts across each coil, holding full load current in one leg constant; then hold the volts across one coil constant and read the current in all three legs. Then take the drop across each leg, holding full load current in each leg, and reading the volts drop. This also must be done at 50 per cent. overload. The frequency must be held constant while the drop is being taken, as the reactance depends directly on the frequency. When the reactive coil has reached constant temperature at normal load, run two hours at 50 per cent. overload.

When the heat run is finished take air readings and test the insulation. The insulation tests consist of double potential for one minute, and one and one-half potential for five minutes, and high potential tests. The high potential test must be applied between the winding and core, between the winding and frame, and between the phases.

Resistance

Resistance is measured as on transformers.

Polarity Test

Polarity test is made by supplying direct current to the middle phase and noting deflection, then transfer the drop lines to the corresponding terminals of the other phases and note the kick on breaking the current in the middle phase.

On oil cooled reactances, take the temperature of the core, oil and tank. Insulation tests are the same as for the air blast types. Inspect the tank and oil gauges for leaks.

As all the other reactive coils, as type RE, are special, special instructions are necessary for testing. In all cases tests depend upon the conditions under which the apparatus will operate.

TRANSFORMER CONNECTIONS

When considering transformer ratios, take the actual voltage of either primary or secondary as one of the factors. Thus, if
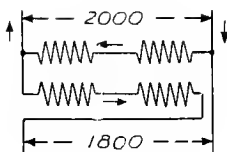
Fig. 117
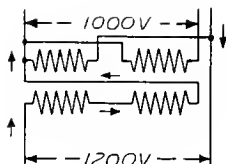
Fig. 120
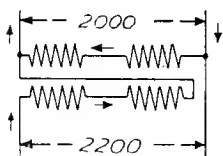
Fig. 118
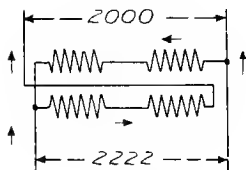
Fig. 121
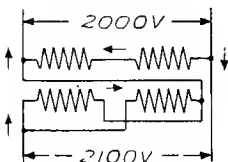
Fig. 119
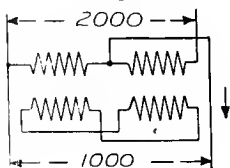
Fig. 122

Fig. 123

Fig. 124

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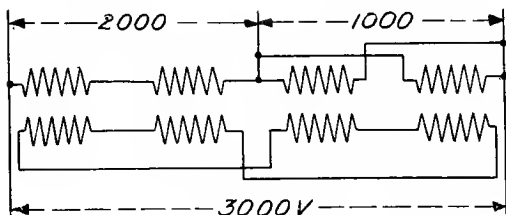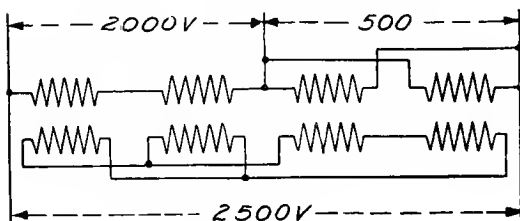
100 volts is the secondary voltage, the ratio should be considered as 1000 to 100 rather than 10 to 1. The ratio then tells what voltage is safe to use on the transformer, and the wrong potential is not likely to be impressed, which might burn out the coils or injure the insulation.

In transformer combinations, see that the windings are not overloaded. 60 cycle transformers when used on 25 cycles should not be operated at more than 75 per cent. of the rated voltage. In the following, transformers with two 1000 volt primary coils and two 100 volt secondary coils are taken as the basis.

Single-Phase Connections

Fig. 117 shows the connections for decreasing the voltage 10 per cent. Fig. 118 shows connections for a corresponding increase. Fig. 119 boosts from 2000 volts to 2100 volts. Fig. 120 boosts from 1000 volts to 1200 volts.

By changing the secondary connection of Fig. 120 the line voltage can be lowered. The amount of current that this arrangement will "boost" or "lower", depends only upon the capacity of the secondary. By using two or more transformers, practically any voltage may be obtained. If a fine adjustment is desired, the secondary and primary may be connected as shown in Fig. 121.

Fig. 122 shows a step-down 2:1 compensator connection. This may be used as a step-up 1:2. The secondaries are connected in multiple to reduce the impedance between the primary coils. The above combinations are made when using one transformer.

Fig. 123 shows step-up 2000 to 3000. This may be used as step-down 3000 to 2000 or 3000 to 1000.

Fig. 124 shows the connections for 2000 to 2500, as a step-down 2500 to 2000, or 2500 to 500. These combinations employ two transformers.

In compensator connections the capacity is governed by the capacity of the coil in series with one side of the line.

By increasing the number of transformers, or by using transformers with a large number of coils, the number of combinations may be increased almost indefinitely.

Three-Phase Connections

The straight three-phase connections gives the following ratios:

Primaries	Secondaries	Ratio
Series Y	Multiple delta	3460:100
" "	Series delta	3460:200
" "	Multiple Y	3460:173
" "	Series delta	3460:346
Series delta	Multiple delta	2000:100
" "	Series delta	2000:200
" "	Multiple Y	2000:173
" "	Series Y	2000:346

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Primaries	Secondaries	Ratio
Multiple Y	Multiple delta	1730.100
" "	Series delta	1730:200
" "	Multiple Y	1730:173
" "	Series Y	1730:346
Multiple delta	Multiple delta	1000:100
" "	Series delta	1000:200
" "	Multiple Y	1000:173
" "	Series Y	1000:346

It is often desirable to slightly "boost" or "lower" the voltage of an alternator. This is done in the same manner as on a single-phase circuit, the primaries being connected in Y or delta and the secondaries in series with the circuit. See Fig. 125. A great many variations of "boost" and "lower" may be obtained by putting coils in multiple or series. The secondary coils may be connected all in multiple or all in series.
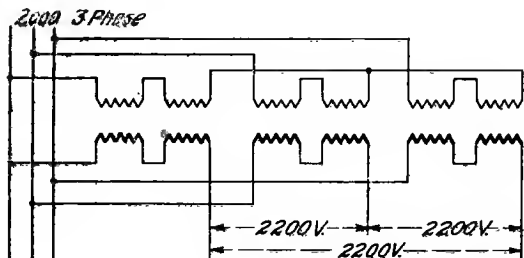
Fig. 125

Fig. 126 shows a 2:1 step-up or step-down compensator connection. The transformers must have two secondaries which must be connected in multiple in order to prevent excessive magnetic leakage between primary windings.

Fig. 127 shows a step-down combination with a delta inside a Y connected secondary. If the primaries of each transformer are connected in multiple the following capacities are available, 100 per cent. at $264\frac{1}{2}$ volts; 50 per cent. at 100 volts; and 50 per cent. at $264\frac{1}{2}$ volts with 50 per cent. at 100 volts. With the primaries of each transformer in series 100 per cent. capacity at $264\frac{1}{2}$ volts is possible. A delta inside a Y may be used on the primary to step down from 2645 volts to 1000 volts; the secondaries of each transformer, however, must be connected in multiple.

The ratio of transformation of the delta inside a Y, is easily calculated by trigonometry.
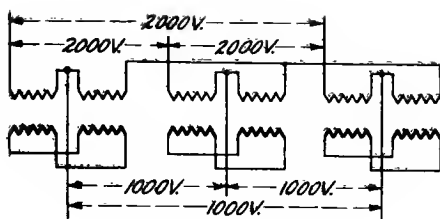
Fig. 126
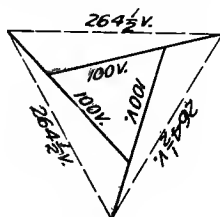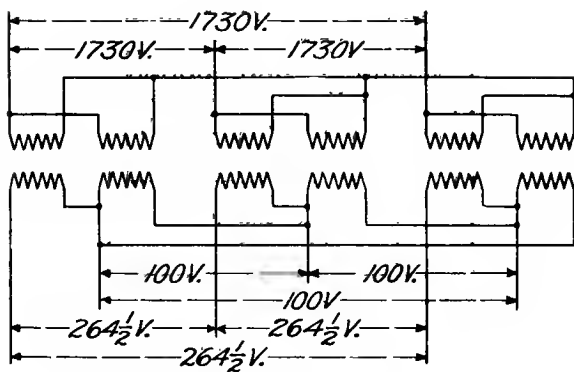
Fig. 127

Six-Phase Connections

In transforming from three-phase to six-phase the double Y, the double delta and the diametrical connections are used. The double Y is shown in Fig. 110.

The double delta is shown in Fig. 128.

The diametrical connections are shown in Fig. 111.

In checking up double Y connections the neutrals should be connected together so that the hexagonal voltage may be obtained. This is also advisable on the diametrical connection if transformers are used that have two coils in the secondary winding, or have a 50 per cent. tap in the secondary. The ratios of voltage are calculated in the same manner as is the case for three-phase connections.

Six-Phase △
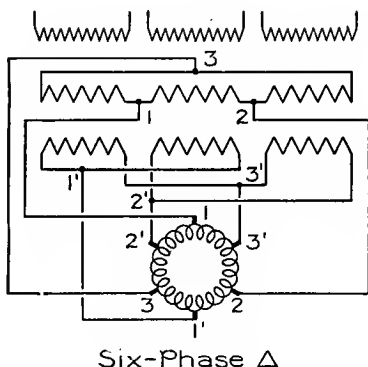
Fig. 128

Three-Phase to Two-Phase Transformation

The "Scott" connection is used a great deal in transmissions and distributions. (See Fig. 129.) One transformer is called the main, and the other the teaser. Two transformers are required. They are made exactly alike, so that they can be interchanged. The winding is provided with a 50 per cent. tap and with taps so that 86.6 per cent. of the winding may be used. Connections 1–2–3 are for the three-phase circuit, A' A and B-B are the phases of the two-phase circuit. Reference to the diagram explains the reason for using 86.6 per cent. of the winding of one transformer, and the necessity for the 50 per cent. tap.
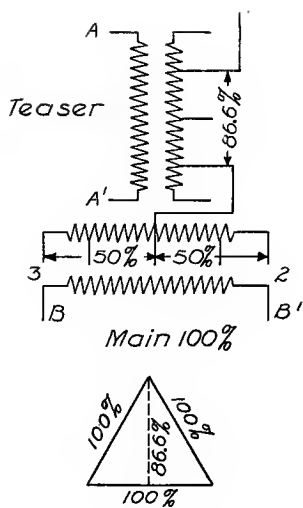
Fig. 129
SCOTT CONNECTION

STEAM TURBINES

Nomenclature

The steam turbine differs radically in construction from any other prime mover and includes many parts heretofore not familiar to steam engineers. If various names are used for the same parts, uncertainty, annoying delays, and sometimes needless expense are likely to occur. Figs. 130 and 131 show the proper designation of the principal parts of the Curtis Steam Turbine manufactured by the General Electric Company. By studying the cross section drawings of the turbine, they can be used for machines having a different number of stages and wheels per stage.

Explanation of Fig. 130

1   Upper bearing bracket
2   Middle bearing bracket
3   Upper bearing
4   Middle bearing
5   Middle bearing cap
6   Armature flange
7   Binding bands
8   Brackets (revolving field)
9   Stirrups
10   Field sleeve
11   Oil pan (upper bearing)
12   Oil deflector (upper bearing)
13   Armature coils
14   Base for generator
15   Oil pan (middle bearing)
16   Oil deflector (middle bearing).

Explanation of Fig. 131

1   Head
2   First diaphragm
3   Second diaphragm (nozzle diaphragm)
4   Third diaphragm (nozzle diaphragm)
5   Turbine shell
6   First stage nozzle
7   Second stage nozzle
8   Exhaust or condenser base
9   Wheel spider
10   Wheel disk—first
11   Wheel disk—second
12   First row of wheel buckets
13   Second row of wheel buckets
14   First diaphragm packing ring
15   Second diaphragm packing ring
16   Third diaphragm packing ring
17   Wheel spider
18   Wheel disk—first
19   Wheel disk—second
20   First row wheel buckets

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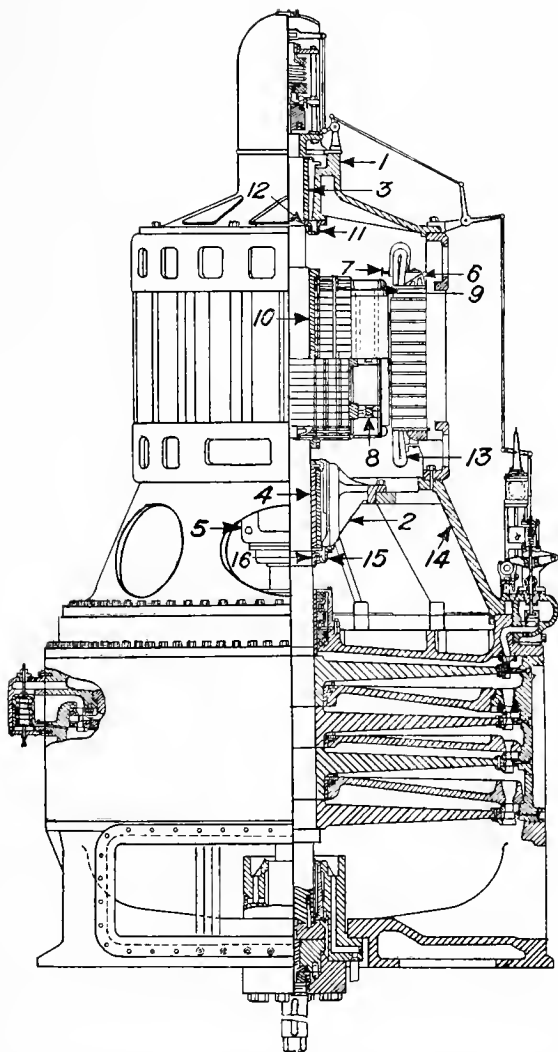
Fig. 130
HALF CROSS SECTION OF TURBINE AND GENERATOR

21 Second row wheel buckets
22 Intermediates—first stage
23 Intermediates—second stage
24 Intermediates—third stage
25 Intermediates—fourth stage
26 Shaft.
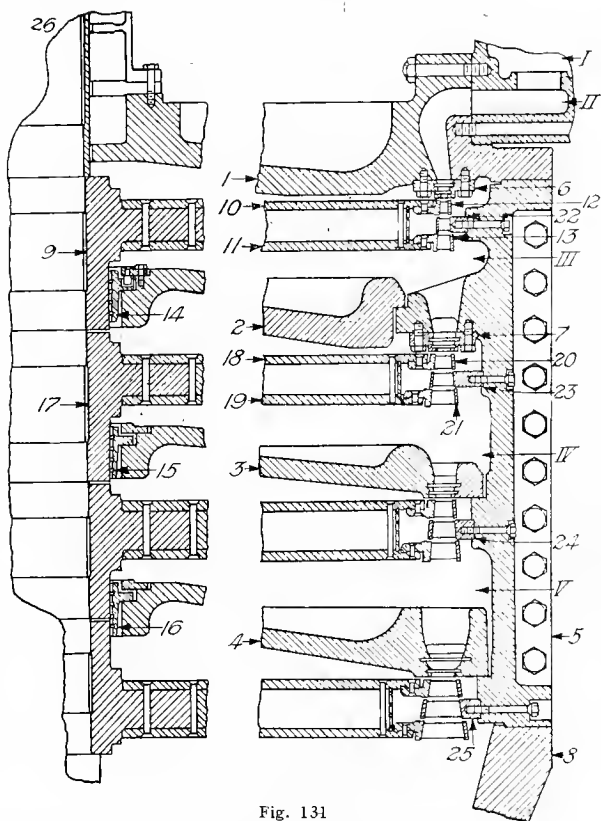
Fig. 131

CROSS SECTION OF TURBINE

The tests which are usually made on Steam Turbines may
be included in two classes, "Commercial Tests" and "Special
Tests."

Commercial Tests

In this test the turbine is run non-condensing. It is operated
at practically no load without using any definite steam pressure

or superheat. The test consists of dynamic balance, operating governor test at no load and emergency governor test.

In testing apparatus, such as steam turbine generators, it is desirable to assemble the machine complete at the factory and test, for proper assembly, satisfactory mechanical and electrical operation, and, in some of the smaller sizes, for efficiency. The Commercial Turbine Testing Department is organized to do this. The testing apparatus is arranged as simply as possible and is easily understood from the following description:

Oil, Steam and Exhaust Piping and Auxiliaries

Fig. 132 shows plan of turbine test and oil piping. All the oil piping and part of the steam piping is located in a duct that runs part of the way around the test floor. There are four lines of oil piping; the step line; governor line; variable pressure line and an auxiliary line in which water as well as oil may be used for machines operating with water step bearings. The step bearing, governor and water step lines are supplied with taps at every test stand, where vertical machines are tested. The variable pressure line has taps at the stands in the back row only, and does not run in the duct at the front of the test floor. The governor line has the upper bearings and the governor hydraulic piped to it when a low pressure hydraulic is used for the governor valves. The variable pressure line is used when a high pressure (325 lbs. sq. in.) hydraulic is used. The step line has all the oil step bearings piped to it and the auxiliary line is used for the water steps.

The pressure used in the step line is 1150 lbs. per sq. in.; on the governor line it is 120 lbs. per sq. in. It may be varied on the other lines to suit the conditions required. A common drain line is provided for all the oil returning from the machines. It is located in the duct with the other piping and has drain cups piped into it at each stand, where there are taps to the other oil piping. The drain line oil empties into a drain tank and strainer located in the duct near the office.

Steam is piped to the turbine test from the Power House (Building No. 61). The steam main enters Building No. 60 from the steam duct in front of the building and is brought to the test overhead, being supported by hangers on the posts of the building. After entering the test, the main runs along the gallery, then enters a duct and is brought around to the front of the test floor. Taps are made to the main at each test stand. The machines in the back row are connected to the main in the gallery and those in the front row to risers from the main in the duct. An electrically-operated valve is located in the steam main at the point where it enters the test. This valve is placed here in case of emergencies and must be used only as a last resort. This must be remembered as the pressure pumps steam as well as that used on the test floor are controlled by this valve.

Two exhaust mains are provided that can be used on any stand on the test. They run under the gallery and across the

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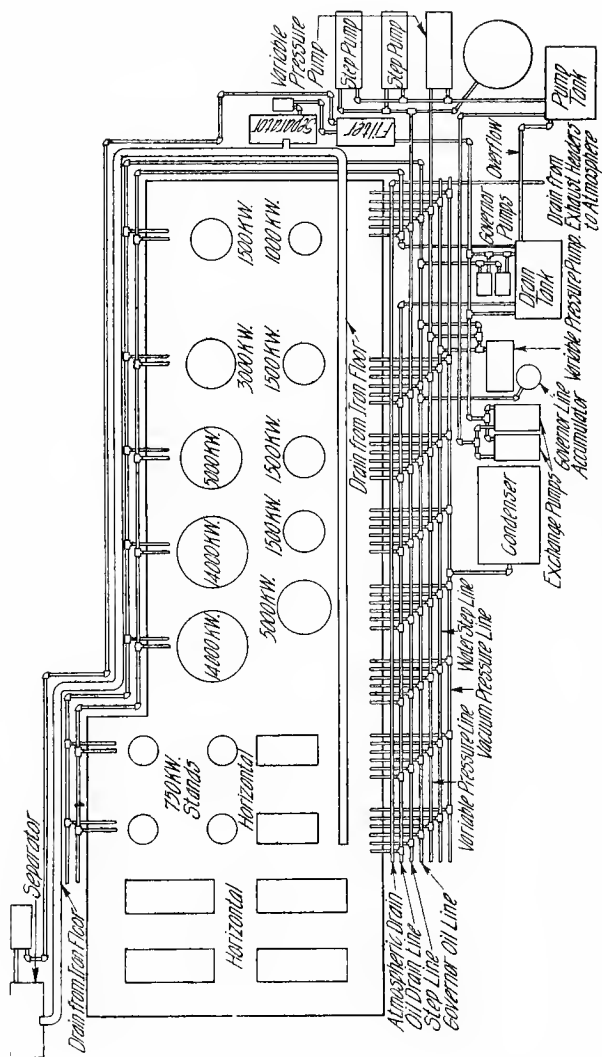
Fig. 132

PLAN OF TURBINE TEST—OIL AND WATER PIPING

test floor at the upper end of the test. The upper main leads to the atmosphere or heating system, and all machines must exhaust into it except those under load. The lower main connects with the Worthington condenser that is located under the gallery. Loaded machines are connected to this main. The exhaust headers at each test stand connect to both mains. A throttle valve is placed between the header and each main so that the exhaust from a machine may be passed into either the atmospheric or condenser mains as required. Drain lines, corresponding to the exhaust mains, are located in the duct and have permanent connections to the exhaust headers. Throttle valves are placed in the taps to these lines so that either one can be used on any machine. The atmospheric drain must of course be used with the atmospheric exhaust and the condenser drain with the condenser exhaust.

Auxiliary Apparatus

The condensing apparatus, oil pumps and accumulators are known as auxiliary apparatus. A regular attendant is in charge of the equipment, which must not be handled by any one else. The condenser (6700 sq. ft.) is located in the duct under the gallery about half way between the upper and lower ends of the test floor. As already stated, it connects to the vacuum line of exhaust piping. The small oil pumps are also located in the ducts near the test office. Taking them in order from the condenser toward the back of the building they are as follows:

(1) The exchange pumps (set of two pumps), which pump the oil from the drains, tank and strainer in the duct to the supply tank in the step pump pit.

(2) The auxiliary pump, in which either oil or water may be used and which may be connected to the variable pressure line, the governor line or the water step line.

(3) The governor pumps (two in the set), which supply the governor line. The small accumulator, which is piped to the governor line, is also located in the duct with the small pumps. This accumulator reduces the pulsation in the line due to the stroke of the pumps and also holds a small reserve of oil under pressure long enough to allow another pump to be connected in case the one in use breaks down.

The step pumps and large accumulator are located in the pit at the lower end of the test. They supply the step bearing line, and the large accumulator is used for the same purpose as is the small one used on the governor line. The pump for the variable pressure line is also placed in the pit with the step pump.

Electrical Equipment

The switch boards on both the turbine and rotary converter tests are used to obtain the proper connections for machines on the turbine test. The letters by which these boards are distinguished are: *A*, High tension board on rotary test. *B*,

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High tension board in gallery on turbine test. *C*, Exciter board, located on the rotary test near the turbine exciters.
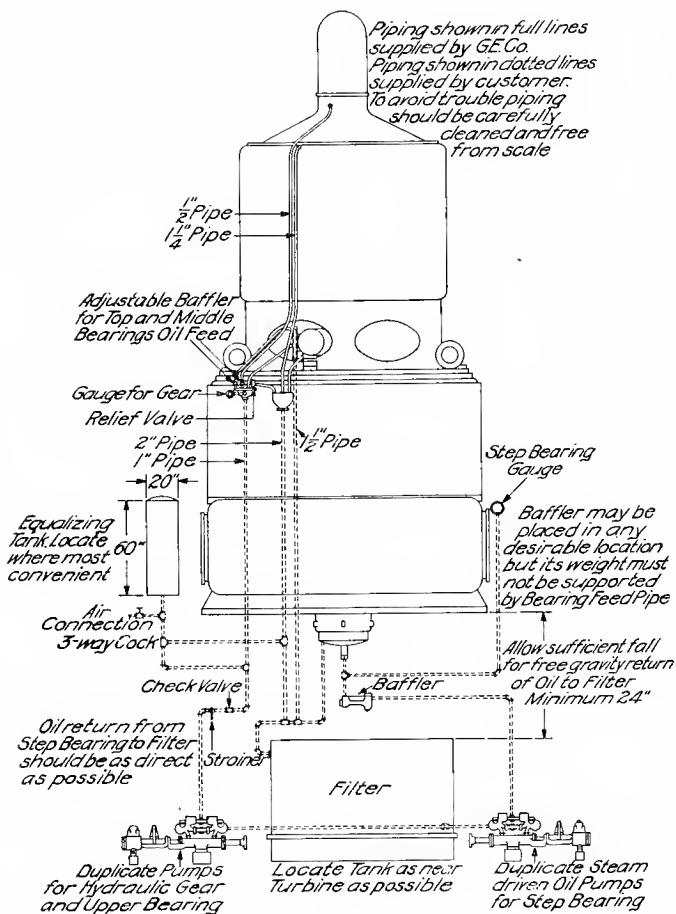
Fig. 133
OIL PIPING OF A TURBO GENERATOR

D, Low tension board on rotary test. *E*, Low tension board in gallery on turbine test. *F*, Low tension board in gallery

on turbine test, which is also wired for the exciter fields and the electrical control on water boxes.

Twelve A.C. electrical stands are used on turbine test which are permanent. Nos. 1, 3, 5, 7, 9 and 10 are located on the floor at the front of the test, No. 11 on the staging for 750 kw. vertical machines, and Nos. 2, 4, 6, 8 and 12 in the gallery.
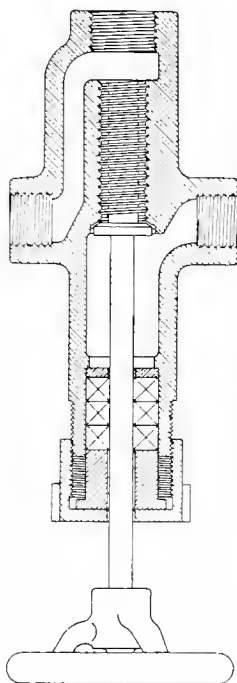
Fig. 134
UPPER BEARING BAFFLER

These stands are equipped with three-phase wiring, that connects with Board B, and with low tension wiring for the field circuits that connects with Board E. The stands are also provided with wiring for the exciter fields and water box control that connect with Board F. Stands are designated by the letter S.

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Preparing Machines for Test

When a machine is first given to the Testing Department, the turbine only is assembled ready to run for wheel balance. Before doing anything on a machine, the man in charge must see that the clearances of the wheels have been taken and a copy of the results given to the Test Office. Look over the oil
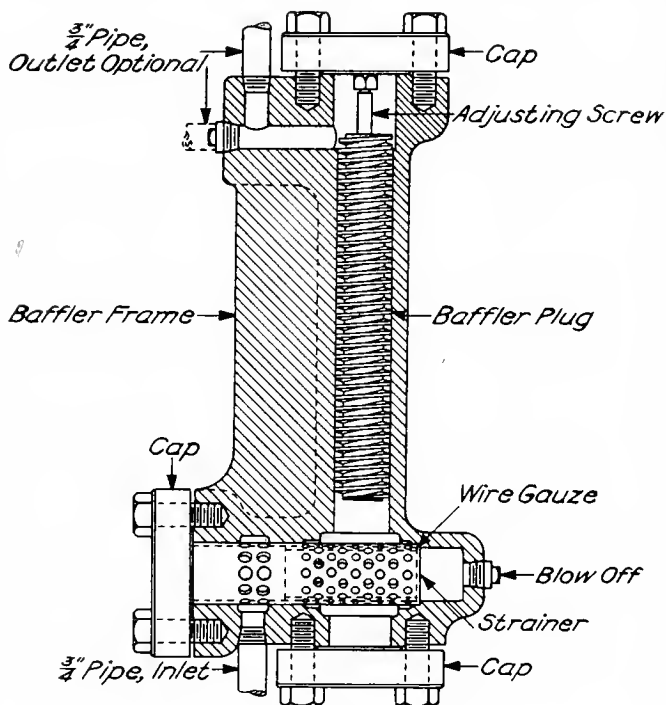
Fig. 135
STEP BEARING BAFFLER

piping on the machine and see that it is connected by the proper taps to the piping in the duct. Fig. 133 shows the oil piping properly completed for a machine ready for generator tests. A machine being tested for field balance must not have the governor hydraulic connected. Long shaft machines (in which the shaft goes through the upper bearing) are piped in the same manner as for wheel balance. Short machines in which

the wheels and shaft are the only parts of the revolving element that are assembled during wheel balance, do not have the upper bearing piped in, since the shaft does not run through that bearing.

Bafflers

Bafflers must be placed in the oil line at every bearing. Fig. 134 shows an upper bearing baffler, and Fig. 136 shows a step baffler. The former is placed on the manifold and the latter should be as near the step as possible and in a convenient place for cleaning when required.

Fig. 135 shows the old style step baffler, which is widely used. It is being replaced, however, by the newer type shown in Fig. 136. This new type baffler has a plug with tapering thread that allows a wide variation of adjustment to be obtained. The drop across baffler and flow is given approximately in the following table. The temperature of the oil is 50° C. or 122° F.

Length of a Drop in Lbs. Pressure per Sq. In.	FLOW IN GALLONS PER MINUTE						
	2	3	4	5	6	7	8
50	1.0	2.2	3.1	4.4	6.0	8.0	12.5
75	1.5	2.9	4.2	5.4	7.6	10.7	16.8
100	1.9	3.4	5.0	6.5	9.0	12.7	20.8
125	2.2	3.9	5.5	7.4	10.1	14.5	24.0
150	2.4	4.4	6.3	8.4	11.2	15.6	27.5
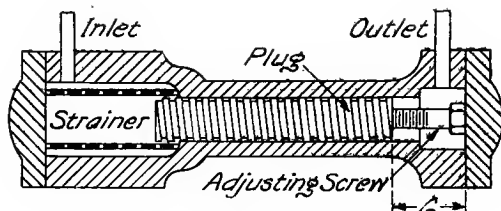
Fig. 136
NEW TYPE STEP BEARING BAFFLER

When oil is first turned on to the step bearing, the following sequence of tests should be made: Turn the oil on very slowly at first until pressure is registered on the gauge, and then wait for a few minutes to note the amount of oil flow. If the step blocks are properly assembled, no flow of oil should occur between them until the operating pressure of the step is nearly reached. If no flow is observed, open the valve until about

one-quarter the required flow is reached and let the steps and pipes warm. This must be done since the oil will not drain away from the step sufficiently rapid to prevent flooding, when cold. The oil is kept at a temperature of 45° C. to 51° C., and should warm up the bearing and drain rapidly. When they are warmed, turn the oil on full (six turns of the valve) and note the flow and pressure. A table of the flow and pressure probable for various machine capacities is given below. This table is calculated for machines that are complete.

RATING		Stgs	Speed	GAL. PER MIN.				LBS. PER SQ. IN.		
Kw.	M.Kw.			Step	Guide	Hyd.	Total	Step	Baf.	Pump
500		2	1800	2	1	1.5	4.5	180	45	225
500		4	1800	3	¾	1.5	3¾	160	290	450
	750	2	1800	3	1.5	2.5	7	260	60	320
800		4	1500	4	1.5	2.5	8	230	65	295
1000		4	1500	4	1.5	2.5	8	250	65	315
1000		4	1200	4	1.5	2.5	8	240	65	305
	1500	4	1500	4	1.75	2.25	8	320	65	385
	1500	4	1800	4	1.75	2.25	8	320	65	385
1500		4	900	4.5	1.5		6	475	425	900
2000		4	750	9	2	5	16	450	90	540
2250		4	900	9	2	5	16	400	90	490
	2500	4	900	4.15	1.5			525	425	950
3000		4	720	12	2.5	6.5	21	560	100	660
	3500	4	750	9	2	5	16	625	100	725
	3750	4	900	9	2	5	16	625	100	725
5000		5	750	15	3	7	25	805	150	955
5000		4&5	500	8	3	5	16	550	120	670
8000		5	750	18	3	9	30	880	150	1030
	5000	4	750	12	3	6	21	900	120	1020
	9000	5	750	15	3	7	25	920	150	1070
	14000	5	750	18	3	9	30	900	150	1050

Step Bearing

Fig. 137 shows a cross section of the step bearing, with the following parts numbered:

1   Revolving step plate
2   Stationary step plate
3   Supporting plate
4   Adjusting screw
5   Threaded bushing for supporting plate
6   Step bearing shell
7   Stud for Part 8
8   Step guide bearing
9   Guide pin
10   Key for Part 1
11   Hardened bushing for stationary disk
12   Dowel stud for driving Part 2
13   Bolt for Part 3
14   Plug for Part 1.
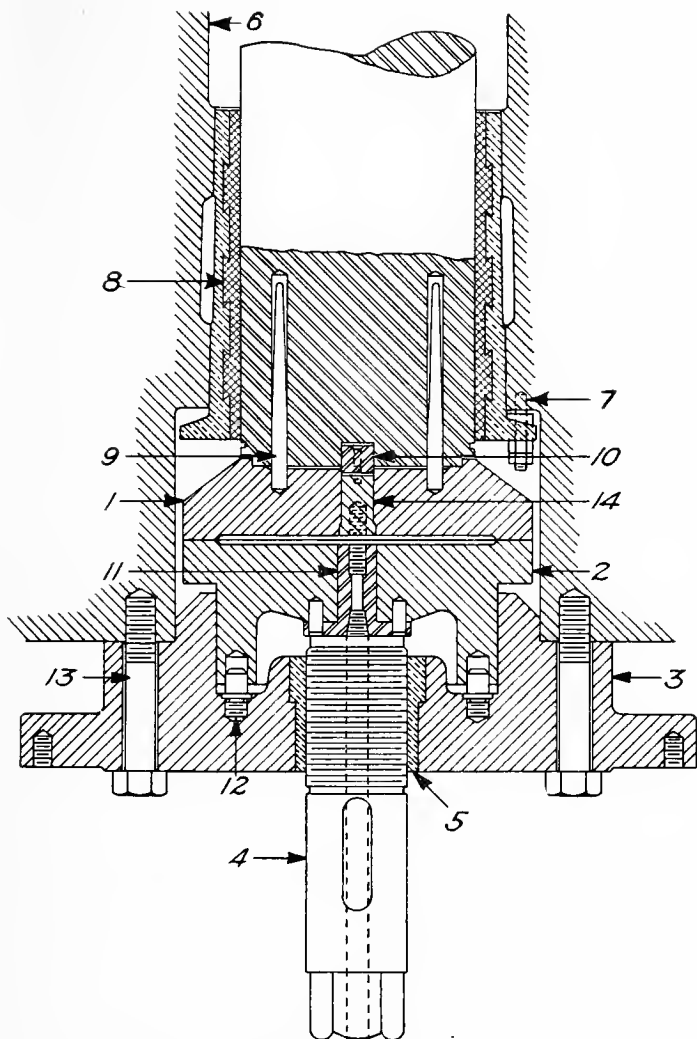
Fig. 137
STEP BEARING

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Oil leaks in the step bearing and its piping occur occasionally, but leaks more often occur in the upper bearings and piping. These are easily remedied and, after once being corrected, no further trouble will be experienced. Turn on oil slowly to the upper bearing (one turn), and watch for leakage. All joints

SECTION A-A-A IN
DIRECTION OF ARROW
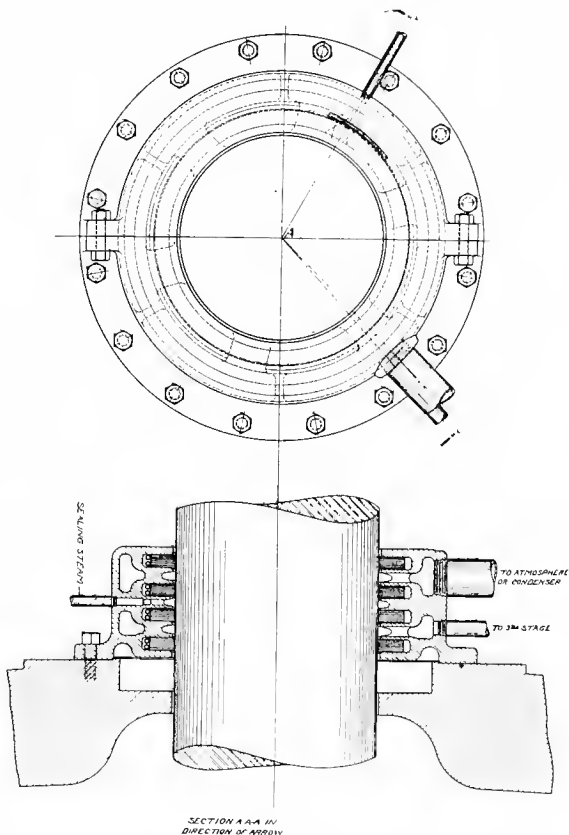
Fig. 138
CARBON PACKING RINGS

and parts through which the oil flows must be watched carefully for leaks. To detect leaks paint the oil pan and bearings and the joints in the pipe with whiting before the oil is turned on. The smallest leak will then immediately be apparent as

the whiting will discolor as soon as oil reaches it. When all joints are made tight, the oil flow must be checked. Never allow a machine to run with insufficient oil on the bearings.

Carbon Packing Rings

The carbon packing rings (see Fig. 138) should have enough steam to lubricate and seal them in case vacuum is used. Too much steam is injurious. The right amount will be indicated by the escape of a little vapor from the drain that leads from the carbon ring casing. Before starting a machine try the trip rigging on the emergency throttle valve to see that it will trip the valve easily. See Fig. 139.

Wheel Balance

Cold machines, in starting, should have enough steam given to them to start revolving immediately. Otherwise the steam may distort the wheels, due to local heating. As soon as a machine starts to revolve, place the end of a wrench against the wheel casing and rest the ear against the other end of the wrench and listen for rubbing. If it sounds free, bring the speed up to about 50 revolutions per minute and then shut the steam completely off. Listen for rubbing as before and at the same time notice whether the speed diminishes rapidly or not. Friction on these machines is very low and, at slow speeds, the windage is low also. Therefore, the speed will not diminish very rapidly when the machine is running slowly, providing everything is working right. A 500 kw. machine (without field) will generally slow down from 50 r.p.m. to a stop in about ten minutes, while a 5000 kw. machine under the same conditions will take from one-half to three-quarters of an hour.

It is not necessary to let the machine come to a stop to see if it is running freely as any marked diminution of speed can be noticed in a minute or two. Heat the machine up thoroughly before bringing to normal speed, by allowing it to run at about one-quarter speed for ten or twenty minutes (depending on the size). When well heated, bring to normal speed (if the balance permits) and note the balance as the machine approaches, and after it has reached normal speed. If the balance is good enough to pass at normal speed, bring it up to 110 per cent. speed and note balance. It should be as good at 110 per cent. speed as at normal.

Some machines are in good balance when they come to test, but more often they have to be balanced dynamically. The best method for doing this is known as the "Cut and Try Method." Paint the shaft with whiting and mark with a pencil when the machine is up to speed. The pencil line will appear heavier in one place which generally is opposite the side that requires weight. Before explaining the method of balancing, the method of numbering the balance holes should be understood. It is impractical to mark the holes themselves, as the steam would soon destroy the marking, so the following method is used. See Fig. 140.

Top of valve

This spring trips valve when retaining latch is released

Tension rod to retaining latch on governor

To avoid an excessive load on trip latch which may prevent valve from closing under emergency conditions do not jam valve spool against under side of cover, but turn hand wheel slightly back from full open position

When shutting down turbine, throttle valve to ½ inch, then trip to insure its proper working condition. Do not tighten packing gland more than necessary

Right hand thread

$\frac{5}{8}$

Lever for hand tripping also to reset coil spring and retaining latch

Turn in this direction to close valve when lever is hooked up, also to raise sliding nut and lever for engaging with hook after valve has been tripped

Section XX

Turn in this direction to open valve when lever is hooked up

Fig. 139
TRIP RIGGING

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A balance weight hole is provided in the wheels opposite (or nearly opposite) the keyway in the upper part of the shaft. Bring this hole under the hole in the diaphragm, through which the balance weights are adjusted, and mark No. 1 on the bearing under the keyway. Revolve the wheels in a clockwise direction (Fig. 140) and each time a balance weight hole comes under the adjustment hole in the diaphragm, mark and number it on the bearing. This will give a counter-clock numbering of the holes themselves. In case there should be more than one keyway in the shaft, the one used as an indicator must be marked. The holes in the bottom wheel are numbered so that No. 1 comes under No. 1 on the top, No. 2 under No. 2, etc.
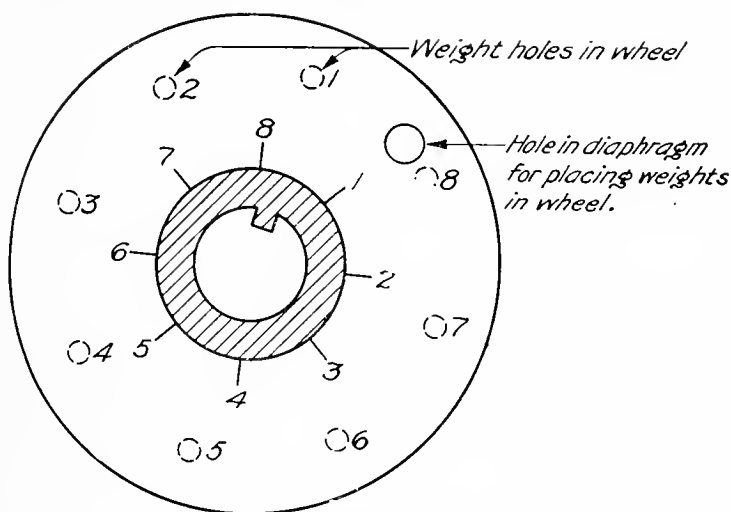
Fig. 140
MARKING OF BALANCING HOLES

The "cut and try method" of balancing consists of a systematic "feel" for balance: A fair sized weight (say a 2 in.) is placed in a balance hole in the top wheel and the machine is sped up and balance noted. The weight is then moved one-quarter way around the wheel and the balance tried again. This process is continued until both top and bottom wheels have been tried. Then trials are made near the holes where the best balance was noted. Sometimes a 2 in. weight is not a good size for a trial weight, and judgment must be used by the tester in respect to this. The per cent. balance on the first shot trial will guide him in selecting a trial weight. A balance record similar to that given below should be kept:

	BALANCE HOLE NUMBERS												PER CENT. BALANCE REV. PER MINUTE					
	1	2	3	4	5	6	7	8	9	10	11	12	1000	1200	1400	1600	1800	1980
T	2																	
B													99	96	95	93	90	
T				2														
B													96	94	90	87	80	
T							2											
B													99	97	97	95	93	
T										2								
B													100	99	99	99	98	
T	2																	
B													98	97	96	95	94	
T				2														
B													99	98	96	93	91	
T							2											
B													96	96	94	93	92	
T										2								
B													99	99	98	98	97	
T										2	1							
B													100	100	100	100	100	100

"T" Top.   "B" Bottom.

From this record it is evident that the quarter of the disc in which to work is the top of No. 10. Change the size of the weights, go on either side of the best trial hole until as perfect a balance is obtained as possible. Sometimes a combination of best shots or trials in top and bottom will improve the balance. In the case above, a 2 in. weight in the top of No. 10 and a 1 in. weight in top of No. 11 balanced the machine.

Wiring and Field Balance

After the wheels are balanced and while the generator is being assembled, the machine must be wired. Find what generator tests are required and wire accordingly. Connect a water box in the armature circuit so that the machine can be stopped quickly when necessary. The field is balanced by the "Cut and Try" method used on the wheels. Number the balance holes beginning with the one nearest the field leads, numbering in a counter-clock direction. The numbers may be written near the holes themselves, instead of being marked on the bearings. It is important to have a system of numbering, so that another tester can take up the balancing where it was left off and continue it intelligently.

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GOVERNOR TESTS

Emergency Governor

This governor is known as Type E and the forms are as follows:

Form A —Compression spring governor
Form B —Tension spring governor
Form C —Clock spring governor
Form D —Ring type governor

Form D is the only one now used, but the others are found on old machines. Type E Form D governor is shown in Fig. 141, in the normal position before operating. The dotted
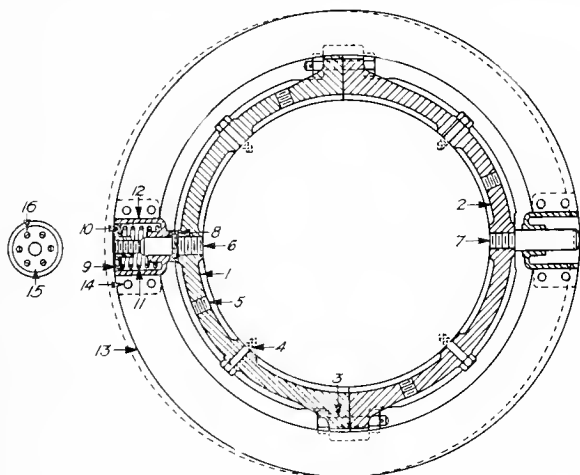
Fig. 141
EMERGENCY GOVERNOR—RING TYPE

circle shows the position after it has operated. The adjusting plate 15 over the spring is threaded in the hole in the center and screws out the spring stud 6. The thread is right handed, so by turning the plate to the right more tension is given to the spring and the speed at which the governor operates is increased. The plate 15 is held in position by a lock screw 16 which goes through the top hole of the circle of holes in the plate and screws into the spring support. This screw must always be replaced after it has been removed, to make an adjustment of the governor. The governor is set eccentric to the shaft and the high point is at the spring support. The following give the eccentricity of Type E Form D governors.

Machine rating.

500 kw.
800 kw. } Not less than $\frac{1}{16}$ in. and not more than $\frac{3}{16}$ in.
1000 kw.

2000 kw.
3000 kw. } Not less than $\frac{3}{32}$ in. and not more than $\frac{5}{32}$ in.
5000 kw.
8000 kw.
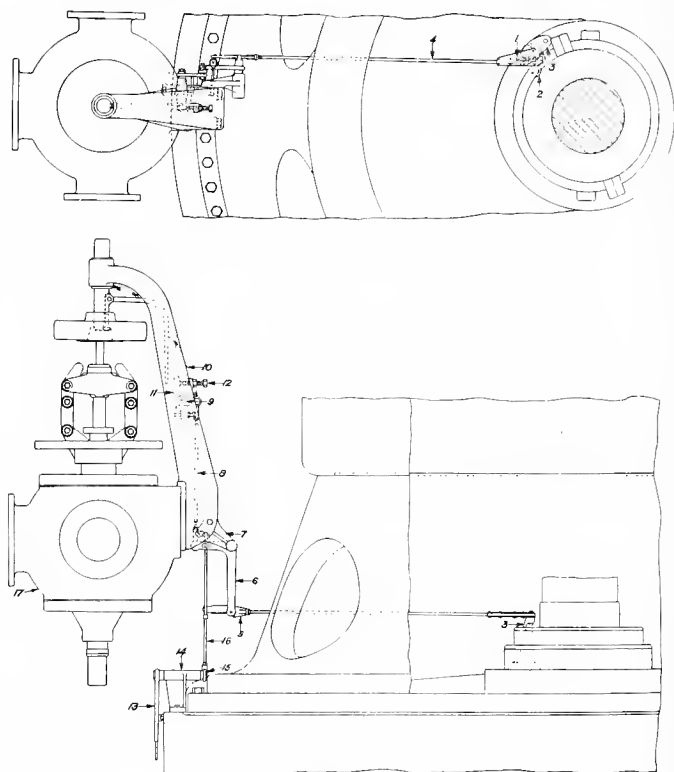
Fig. 142
EMERGENCY GOVERNOR CONNECTIONS

Fig. 142 shows emergency governor connections to the emergency and throttle valve. This is the old type of valve which is giving place to the more modern one shown in Fig. 139. This valve is, however, much used and, as the principles

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of the connections to the governor are practically the same. the explanation given will answer for both valves. The governor must be set to operate at 10 per cent. above speed with an allowable variation of $\frac{1}{2}$ per cent. The trip rigging (if properly assembled) cannot get damaged when the governor operates. It will close the valve immediately.

The rigging and governor must be examined before the governor is operated and again after it has been operated a number of times. Any defects must be reported at once and the necessary changes made. If the valve is working properly,
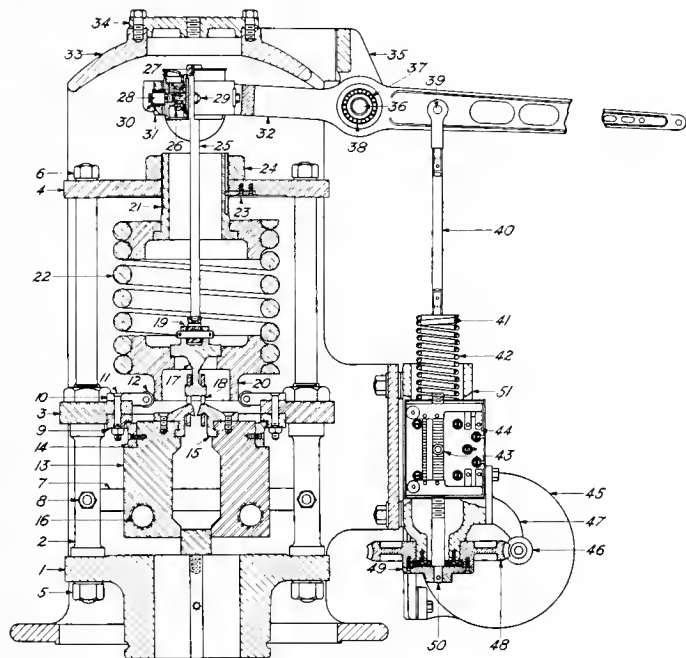
Fig. 143
TYPE M FORM C GOVERNOR

it will shut the steam completely off, when closed. To test it for leakage, close the valves on the machine and trip the valve under test. Then open the drip between the valve and the operating valves, and any leakage will be shown by steam escaping from the drip.

Operating Governor (Main)

The operating or main governor is known as Type M governor and the forms are:

Form A —Ball governor
Form B —Compression spring
Form C —Tension spring

Form C is the latest form of Type M governor and is shown in Fig. 143, numbered corresponding to the following parts:

1 Governor bracket
2 Stud in frame
3 Middle plate
4 Top plate
5 Nut for lower end of stud
6 Nut for upper end of stud
7 Strap for stud
8 Bolt for strap—with nut and lock washer
9 Fulcrum block
10 Guide roller block
11 Bolt for fulcrum and roller blocks
12 Guide roller with pin and cotters
13 Governor weight
14 Knife edge blocks with screw
15 Hook with screw
16 Plug for balance pocket
17 Yoke for links
18 Links
19 Universal joint
20 Lower governor plug
21 Upper governor plug
22 Governor spring
23 Key to upper plug with screws
24 Adjusting nut for upper plug
25 Connection rod
26 Gimball transmission bearing
27 Ball races for Gimball bearing, upper and lower
28 Gimball pivot for box
29 Gimball pivot for beam
30 Bushing for pivots
31 Gimball ring
32 Beam
33 Dome—with bolts
34 Cover plate for dome
35 Bearing bracket for dome
36 Spindle for roller bearing
37 Roller for bearing
38 Bushing for bearing
39 Pin for attaching synchronizing connection to beam
40 Connection for synchronizing spring
41 Upper plug
42 Synchronizing spring
43 Traveling weight for synchronizing spring
44 Limit switch
45 Synchronizing motor
46 Worm for gear
47 Bracket for worm
48 Worm wheel

49   Cap for synchronizing spring
50   Synchronizing screw.

Fig. 144 shows the hydraulic mechanism in connection with the governor.

1   Governor beam
2   Governor connection and floating lever
3   Floating lever
4   Differential connection to floating lever
5   Bracket and guide to pilot valve
6   Operating cylinder
7   Bracket for operating cylinder
8   Cross head guide and lower cylinder head
9   Cross head
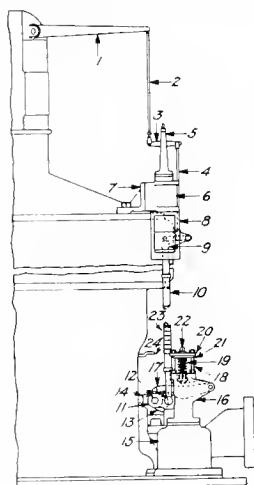
Fig. 144
HYDRAULIC OPERATING MECHANISM

10   Connecting rod to cam shaft
11   Crank for cam shaft
12   Cam shaft
13   Cam
14   Bracket for cam shaft
15   Valve casing
16   Frame for controlling valve
17   Controlling valve lever
18   Stud for spring supporting plate
19   Controlling valve spring
20   Supporting plate
21   Plate for spring adjustment
22   Adjusting screw for spring.

Tests

Fasten a pointer No. 24 on the machine in some convenient place where the pointer will be near the connecting rod (No. 23, Fig. 144), or the rack that meshes with the cam shaft gear. Paint the section opposite the pointer with a coating of whiting. As the valves are opened and closed by moving the pilot valve, make a mark on the whiting opposite the pointer as the first valve begins to open and another mark when the last valve begins to close. Divide the intervening space, between the two marks, into five equal parts, thus obtaining six marks. Readings of speed must be taken as the marks pass the pointer when the machine is brought above speed and again as it falls below speed. A set of readings is thus obtained similar to the following:

| | MARKS | | | | | |
	1	2	3	4	5	6
Accelerating	1532	1546	1560	1570	1580	1591
Decelerating	1530	1542	1554	1568	1575	1589
Lag	2	4	6	2	5	4

Tachometer reading $= 1560$
Speeder on governor $= 1800$

The tachometer on which readings are taken is belted to the shaft of the machine so that the reading is not the actual speed of the machine. The first readings are taken with the synchronizing spring in the middle position and all adjustments of the governor must be made with the spring in this position. The following are the test requirements:

(1) Reading No. 3 must be normal speed.

(2) The first point must be $1\frac{1}{2}$ to 2 per cent. below this speed.

(3) The sixth point must be exactly 2 per cent. above reading No. 3.

(4) The total allowable regulation will then be $3\frac{1}{2}$ to 4 per cent.

(5 On machines up to 1000 kw. capacity the average lag should not exceed .6 per cent. and the maximum .7 per cent. On all machines above 1000 kw. the average lag should not exceed .8 per cent. and the maximum $1\frac{1}{4}$ per cent. Three sets of readings are required with the synchronizing spring in the middle position, and two sets on each of the two positions: Spring all in (maximum tension) and spring all out (minimum tension).

(6) The difference in speed when passing the third mark when reading with the synchronizing spring all in and all out; that is, the synchronizing effect, should be about 6 per cent.

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First Stage

Second Stage

Third Stage
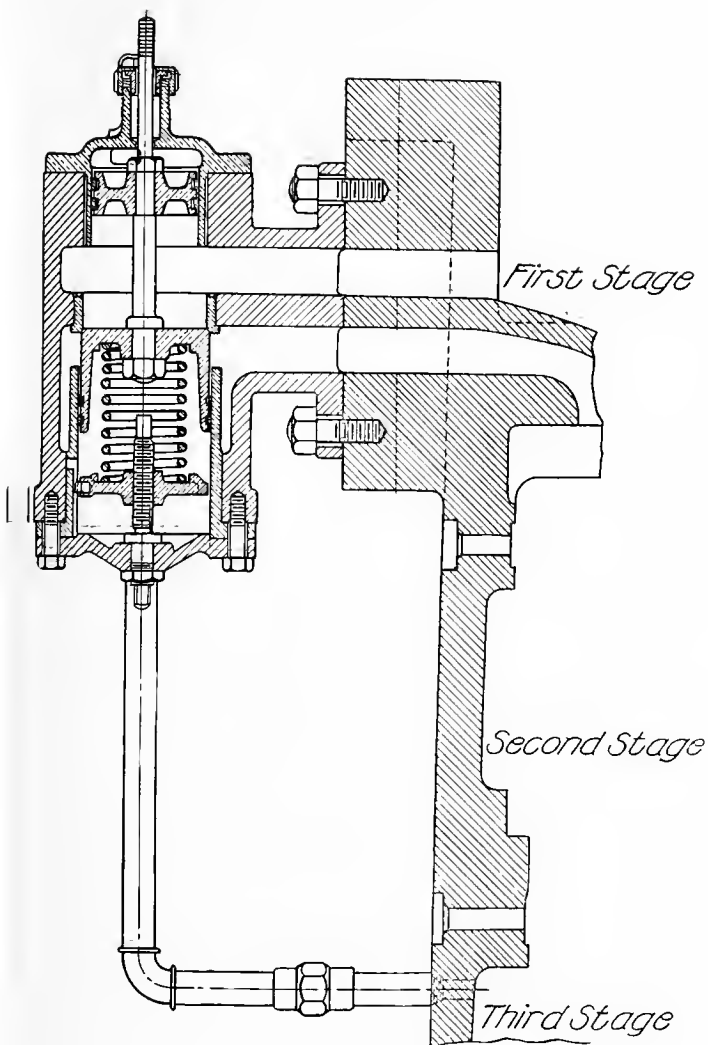
Fig 145
AUTOMATIC STAGE VALVES
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This, however, is changed, now and then, in special cases, and no general rule can be given. If the regulation or speed of the governor is not correct, it can be adjusted by varying the tension on the main governor spring (No. 22, Fig.143), or by changing weights in the pockets of the governor weights (No. 16, Fig. 143).

Automatic Stage Valves

1 Casing for automatic stage valve
2 Valve and piston
3 Valve seat
4 Cylinder lining
5 Spring
6 Spring support
7 Adjusting screw
8 Cylinder head
9 Indicator rod
10 Indicator
11 Stuffing box
12 Gland for Part 11
13 Balancing piston
14 Piston ring for Part 13
15 Piston ring for Part 2
16 Drain pipe.

In the majority of four and five stage turbines, automatic valves are provided which open additional second stage nozzles at overload. Most of these valves are arranged as shown in Fig. 145, so as to open by means of the pressure in the first stage. These valves are balanced by springs and are so proportioned that they open and close within a comparatively small range of the first stage pressure. Pressure on the top of the balancing piston is obtained by a connection to the spring chamber. Leakage passes over to the second stage.

No rule can be given for the adjustment of these valves, since different machines require different pressure distribution. Each valve is provided with an adjusting screw and lock nut, so that the valve can be adjusted and set to suit the conditions required. If any valve sticks or remains partly open during a wide variation of load, the economy of the machine may be seriously reduced. The valves must be adjusted to open and close again, abruptly. Before leaving the factory these valves are assembled on the testing stand and adjusted to suit the operating conditions, as closely as possible.

The testing stand consists of a dummy casing and the necessary steam and exhaust piping. Steam is admitted to the chamber above the piston, the desired pressure being held by a throttle valve in the steam line. The second stage pressure required is held by throttling the exhaust, at the same time admitting steam above the piston. The drain from the spring chamber is open to atmosphere; it is provided, however, with a throttle valve to control the pressure over the balancing piston and the back pressure on the under side of the main piston.

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When an automatic stage valve is assembled, the exhaust pipe and also the drain must be wide open. Steam is then admitted to the first stage and allowed to flow for a few minutes to heat up the valves. The valves are then opened and closed a few times to see that they work all right, and that there are no blow holes in the casing. The exhaust is then partly closed and the drain throttled until the back pressure required on the under side of main piston is obtained. Then the first stage pressure is gradually increased. The first stage pressure is read when the valve starts to open and also when it is wide open. The second stage pressure will of course rise to approximately that of the first stage. When the valve is adjusted to meet the required conditions the adjusting screw is fastened by means of the lock nut. The valves are then taken apart, cleaned, oiled and reassembled before shipment.

Special Tests

These tests are made with the turbine operating condensing, and consist of dynamic tests, operating governor tests, under load; emergency governor tests, water rate tests under the required conditions of vacuum, superheat, steam pressure and load.

Special tests are occasionally taken to check guarantees made to the customer. Special tests are also sometimes made to obtain engineering information on new or special machines. In order to take care of this work, of which the principal test is the efficiency or water rate test, the testing section in Building No. 61 is equipped with apparatus especially arranged for making these tests.

The load of steam turbines on which water rate tests are made, is always obtained from the generator direct connected to them. These generators are connected to batteries of water boxes of sufficient capacity to dissipate the energy without excessive heating. In the case of alternating current generators, the energy is measured by wattmeters as already described. Where direct current generators are in question, volt and ampere readings are only necessary to determine the energy output.

Turbine casings must be drilled and piped so that pressures can be read in each stage. The pipes furnishing steam for sealing the carbon packing rings should be fitted with a calibrated orifice, so that the amount of steam required to seal the rings can be determined. This steam must not be deducted from the total amount, it is only required as a check on the condition of the rings during test. In making water rate tests, the exact condition of the steam used, as regards pressure, superheat, etc., must always be carefully determined. It is also important to determine the condition of the steam within the various turbine stages.

Before starting a water rate test good balance must always have been obtained; the carbon packing rings must not show excessive leakage and they must seal properly under vacuum. The governor must give perfect regulation and show no tendency

to hunt. All conditions affecting operation must be so made as to insure a successful and continuous run.

After the turbine has been connected to its condenser and has been started for the first time in the test stand, the proper vacuum cannot always be obtained. Some time, therefore, is generally required to eliminate air leakage through condensers, or turbine casings, and connection pipes forming the vacuum chamber. In most cases the principal leakage occurs at the connecting surfaces. To locate air leakage, apply a steam pressure not exceeding 5 lbs. per sq. in. to the condenser and connections, at the same time noting if any water oozes from the connections.

In doing this the turbine and condenser should first be drawn full of air. The dry vacuum air pump is then shut down, but the hot well and the circulating water pumps are kept running. The step pressure should be off, the bearing oil on, and all the controlling valves open. If the condenser is not first filled with air, or only part of the valves are opened, the steam pressure required may be sufficient to rotate the turbine. The pressure should be applied very slowly, and when a pressure of 3 in. or 4 in. of mercury is reached, all joints and possible flaws in the castings should be gone over and leaks noted.

Leaks that cannot be closed by tightening the bolts, should be subjected to a vacuum and the leaking joints then painted with black japan that has been allowed to air dry until quite thick. Fresh japan should not be used as it may either run off or be drawn into the turbine through the leak. Only known leaks should be painted, since dry japan can only be removed by burning off with a blow torch. Putty is of no use in stopping a leak, as it will soon dry and crack away from the iron, causing a leak that is very hard to locate. "Smooth on" mixed with linseed oil may be used on a permanent joint, but as this joint can only be broken with a cold chisel and hammer it should only be sparingly used for temporary work. A bad leak may be closed by caulking with lead or solder, and afterward painting with japan. A small kerosene torch will aid the determination of a leak as the blaze will be deflected when carried near the leak.

Initial pressure is held constant by throttling down the steam, at boiler pressure, with a gate valve. Pressure is read on a gauge located between the boiler and the emergency valve and as close to the latter as convenient. This pressure is known as the "pipe pressure" and is recorded at two minute intervals during the test. The man holding this pressure should at once notify the man in charge of the test if the pressure cannot be held constant.

Steam coming from the boilers is highly superheated. This is regulated by injecting a spray of water into the steam main at a considerable distance from the turbine in order to get a good mixture of the steam and water. Where the superheat required is high, its temperature is used in the test, but when dry steam is specified about 15° superheat is used which is

afterwards corrected in calculating the water rate for dry steam. This is done in order to insure the steam being dry; for if a lower superheat is used the temperature is likely to drop to the saturation point, where its condition cannot be determined without a calorimeter.

The water for injection is taken from the condensed steam, after it has been weighed. It is supplied at a pressure of 300 to 400 lbs. per sq. in. by a duplex pump equipped with a governor. The quantity of water is regulated by a hydraulic valve, and the temperature read on a specially calibrated Fahrenheit Thermometer, located in a mercury filled thermometer well, near the point at which the pipe pressure is read.

The thermometer well can be made out of a piece of $\frac{1}{4}$ in. iron pipe slightly shorter than the diameter of the steam main. One end is plugged with a $\frac{1}{8}$ in. iron pipe plug riveted in, and the other end is screwed into a $\frac{1}{2}$ in. x $\frac{1}{4}$ in. iron bushing. See Fig. 146. Brass should never be used, as the mercury will act on it and it may, therefore, blow out at any time. Before inserting the thermometer it should be examined carefully to see that the mercury column is not separated in the neck or stem. If in this condition, the thermometer must not be used.
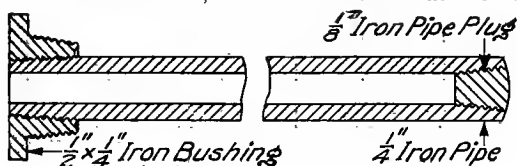
Fig. 146
THERMOMETER WELL

Be careful to use a thermometer of sufficient range to prevent the mercury column rising too far and breaking the bulb. The thermometer should be removed from the well and returned to its case when not in use.

Pressures

The pressures generally read (see Fig. 131) are:

    Pipe pressure
    Valve casing — I
    1st stage bowls—II
    1st stage shell—III
    2nd stage shell—IV
    3rd stage shell — V
    Exhaust.

The location and reading of the pipe pressure gauge have been described.

The valve casing gauge may be piped into the valve casing anywhere above the controlling valves, but should generally be on the end opposite to the steam entrance. This pressure serves as a check on the pipe pressure and gives the drop of pressure through the emergency throttle valve. Two minute readings are taken.

The bowl pressure is taken on the steam passage between each of the controlling valves and the 1st stage nozzle. The bowls are numbered in the order of their opening, the first one to open being No. 1. The pressure on this bowl is read as well as the pressure on the bowl on which the governor throttles, both readings being recorded every two minutes. Knowing the area of the nozzles open, the theoretical steam flow can be calculated and used to check the flow recorded.

Stage shell pressures are read on each stage just below the wheel and above the diaphragm for the next stage. The first stage should be equipped with both a siphon and a quill, to read either pressure or vacuum. If there are more than four stages the second stage may need a similar equipment but the lower stages only need a quill. The 1st stage pressure is
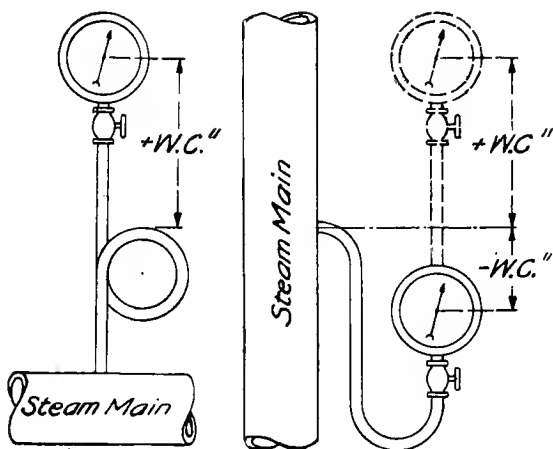
Fig. 147
WATER COLUMNS ON GAUGES

read at two minute and the lower stages at four or six minute intervals.

The quill for the exhaust pressure should be tapped into the connection between the turbine and condenser close to the exhaust opening of the turbine.

Gauges are used to read all pressures above atmosphere, and they should always be calibrated with a dead weight tester, both before and after test. Before shutting down, except in case of an emergency, all gauges should be shut off to prevent being subjected to a vacuum. If this occurs, the needle may be drawn back against the stop pin so forcibly as to alter the calibration. The calibration may also be changed by sudden jars or by heating. To prevent the latter, all gauge piping

must be equipped with a siphon, which is kept cool by applying wet waste. If a gauge is allowed to heat up, the solder in the Bourdon spring will melt and ruin the gauge.

The water column on the gauges should be measured and entered on the testing Record Sheet with the number of the gauge. The water column is measured from the top of the siphon coil to the center of the gauge and recorded as + or — W C in inches. (See Fig. 147.)

U tubes are used to read all vacuum and pressures of a few inches. These consist of a thick glass tube with an ⅛ in. bore bent in the shape of a U, and mounted in a wooden case
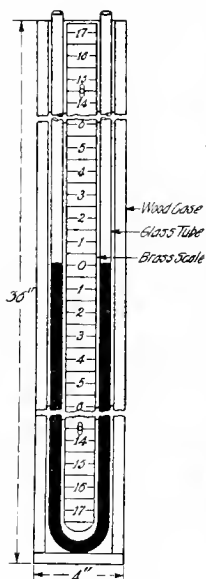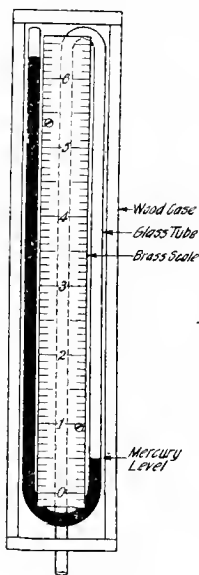
Fig. 148   Fig. 149

carrying a brass scale. (See Fig. 148.) The scale is graduated in inches with the zero at the center and numbered each way to read at least 16 in. The tube is then filled with mercury. The U tube is connected up through a heavy rubber tube. The glass tube should be clean and free from water and the connections should be free from air leaks. These may be detected by turning the cock off, leading to the vacuum being measured, and noting if any perceptible fall of the column occurs. Both columns should be read and added together. Never read one and multiply by two. When the U tube is disconnected both

columns should stand at the same level. When reading vacuum the U tube may be left connected to the machine, but it should be disconnected after each pressure reading, or the tube will gradually fill with water.

Absolute pressure gauges are used only on the high vacuum of the exhaust, to check the U tube. This is made of a thin glass tube bent in the shape of a U with one end longer than the other. The longer end is bent over and brought down below the bottom of the U. (See Fig. 149.) The short leg of the U and a couple of inches of the other leg is completely filled with mercury, which is then boiled out and the top sealed. The whole tube is then mounted in a wooden case carrying a brass scale graduated in inches. The lower end is connected to the vacuum to be measured by a heavy rubber tube. Normally the difference in the heights of the two columns will be six to eight inches, but with a high vacuum on the lower end they will tend to equalize. The upper column has an absolute vacuum on it so that the difference in the height of the two columns represents the difference between the vacuum being read and an absolute vacuum, or the *absolute back pressure*. The sum of the readings on the absolute gauge and the U tube should check the barometer reading within less than 0.1 in.

The mercury in the end open to the atmosphere slowly oxidizes and when this takes place the absolute gauge will record a smaller back pressure than is actually present. The gauge should be placed above the opening into the vacuum space and the rubber tube kept free from loops or water may lodge in it and be carried over on the top of the mercury when the vacuum is broken. If this occurs, the gauge must be sent to the laboratory and cleaned and refilled. The gauge must always be kept in a vertical position and never laid down or carried horizontally, or air will get into the sealed end. Turn on to vacuum very slowly and never take it off suddenly, or the mercury may break the sealed end.

Flow Tanks

After the steam has been condensed in the surface condenser it is pumped from the hot well to the flow tanks where it is weighed. These tanks should be of sufficient capacity to hold the amount of steam condensed during six minutes. They are mounted one above the other. Both outlet pipes should be equipped with quick closing valves which shut perfectly tight. The upper tank is used as a reservoir, when taking weights on the lower, which is mounted on a pair of platform scales.

To measure the amount of condensed steam, proceed as follows: Close the upper tank outlet valve on an even six minutes. Then close the lower tank outlet and balance the scale. This reading is called "tare." The upper valve is then opened, and closed after exactly six minutes have elapsed from the first closing. After closing, the scale is again balanced, and this reading is called "gross." The difference between the "gross" and "tare" is the "net" reading which when multiplied

by 10 gives the flow per hour. After taking the "gross" reading, the lower valve is opened and the water allowed to run to waste. The valve is then closed and the "tare" again taken. This cycle is repeated as long as the test continues, care being taken to close the upper valve at exactly each six minute interval. If the flow is extremely rapid, readings may be taken at four or even three minute intervals. Slight variations will occur due to irregular pump or condenser action, but the average of a number of readings will give accurate results with constant conditions. At least five readings should be obtained for each load, or operating condition.

Before taking any readings, the scales should be carefully inspected to see that the platform and the scale beam move freely. The scales should be calibrated frequently. This can be done by balancing the scales and then adding a 50 lb. standard weight. These should be placed on each of the four corners of the platform. The scales should be thoroughly overhauled occasionally and all knife edges kept sharp. When not in use, the weight should be taken off the knife edges, by throwing the lever to the off position.

Tables

The meters required on the tables for testing three-phase A.C. generators are: two wattmeters, three A.C. ammeters, two A C. voltmeters, one D.C. ammeter and a D.C. voltmeter. The wattmeters have a capacity of 5 amperes and 150 volts, or 500 watts; the ammeters read to 5 amperes and the voltmeters to 150 volts. The D.C. instruments are used on the field circuit.

Each A.C. instrument is provided with a separate potential or current transformer, of sufficient ratio to bring the reading well within the scale of the meter. Five current and four potential transformers are required. (See Fig. 150.)

One side of the current transformer secondary is grounded and each circuit is provided with a single-pole single-throw short circuiting switch, which must be used when the meter is disconnected. The volts, amperes and watts are read, using a separate transformer, to check the correctness of the load and the power factor, which should be greater than 0.99; otherwise the test cannot be accepted. The meters and transformers should be calibrated frequently, and a copy of the calibrations kept at hand for calibrating the load. A record of the number and date of calibration of each meter, and the number, ratio and date of calibration of each transformer used, should be entered on each sheet of every test.

The tester reading the wattmeters is responsible for the load, and, assisted by the man reading the ammeters, must keep the phases as nearly balanced as possible. Readings are taken at two minute intervals, at the former's signal. All meter readings should be taken as nearly simultaneously as conditions permit. The man reading voltmeters must hold the voltage constant by varying the field, when the governor

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is operating, and must read and record volts field and amper field, at four minute intervals.

A generator with an AQB rating requires one less curren transformer and A.C. ammeter. On D.C. generators, two se of millivoltmeters, with shunts, and two voltmeters are use to check the load. A great deal of trouble is often experience in getting shunts that will check within 1 per cent., after the have been heated. The readings must, therefore, be watche very carefully. Field amperes and volts should be recorded a four or six minute intervals.

Tests

The tests generally required are load curve and no loa flow (water rate) with field excited and vacuum curves at variou
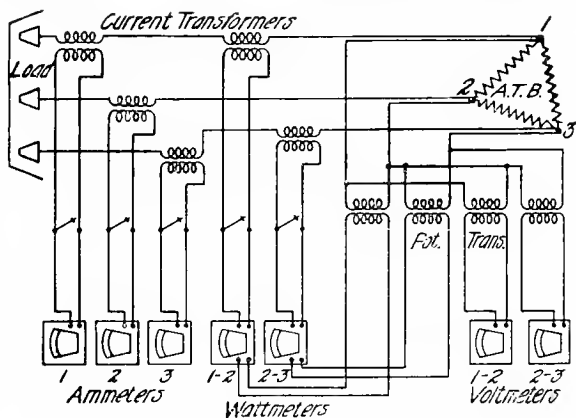
Fig. 150
WIRING CONNECTIONS FOR LOAD TEST

loads. Speed curves at maximum load non-condensing ar also required. The following may also be required: Bow pressure curve; superheat curve; shell pressure curves. Th operating constants standard for the majority of machines ar 150 lbs pipe gauge pressure, 28 in. exhaust, and 0° C. superheat Any or all of these may be varied to suit the operating condition required.

In taking a *load curve* (water rate with load) with the gover nor operating, the initial pressure, superheat and vacuum ar held constant and at least three, and preferably five, loads ar used. These may be half, full and 50 per cent. overload wit the quarter and 25 per cent. overload On maximum rate machines, half, two-third and full load are commonly required No load flow (water rate) is taken by taking off all the loa

and holding the normal voltage under the same steam conditions. The readings taken and the time intervals are as follows:

```
Pipe pressure.............................2 minutes
Valve casing..............................2      "
1st bowl..................................2      "
Throttling bowl...........................2      "
Superheat.................................2      "
1st stage shell...........................2 or 4 minutes
2nd   "    "    .........................4 or 6      "
3rd   "    "    .........................4 or 6      "
Additional shells.........................4 or 6      "
Exhaust-vac. and abs......................2 minutes
Packing steam exhaust and head if used...6 to 10 minutes
Temperature of all U tubes...............10 minutes
Flow (water rate) ........................6      "
A.C. watts   ⎫
A.C. amperes ⎬ ........................2      "
A.C. volts   ⎭
Field amperes and volts 4 minutes
D.C. amperes ⎫ ........................2 minutes
D.C. volts   ⎭
```

A·vacuum curve may be run with or without the governor. When the governor operates, the initial pressure, superheat and load are held constant and the vacuum varied. For a short vacuum curve four or five points are taken at pressures varying 1 in. If it is desired to carry the test to atmospheric pressure, two or three of the higher vacuum readings are taken close together and the pressure differences then gradually increased to five or six inches at atmosphere. The same readings are taken as on the load curve.

In running a *vacuum curve* without the governor, a number of valves are blocked open to give approximately the desired load at 28 in. vacuum. The speed is held constant by varying the load and readings taken on the table, only when the speed, initial pressure, superheat and vacuum are correct. They are then taken at 1 minute intervals. All other readings are the same. The field amperes are held at the constant value, which gives normal voltage at normal speed. The water flow will be constant at the given vacuum, so that the vacuum can be changed as soon as a sufficient number of steady readings on the table are obtained. Seldom more than four points are taken, at 1 in. pressure differences.

This test and the speed curve are the two most difficult water rate tests to make. Every man must work together, or the speed will continually vary and no results be obtained. The load should be varied in small increments and sufficient time allowed for a corresponding change in speed. The field amperes should be held absolutely constant as but a small change in excitation produces a large change in the load, especially on high voltage machines.

On a *speed curve*, the conditions are similar to that in a vacuum curve without governor and the same precautions apply. The speed is varied by varying the load, and field amperes are held constant to give normal voltage at normal speed If, however, at the higher speeds the voltage is too high either for the safety of the windings or for the meters, the excitation may be reduced sufficiently to enable readings to be taken.

Maximum load non-condensing may be taken from a point on the normal load vacuum curve by a separate test. Occasionally back pressure curves above atmosphere are required.

If the turbine has no atmospheric exhaust openings the back pressure test can be obtained only by throttling down the air pump until atmospheric pressure is obtained at the exhaust opening of the turbine. This produces a high temperature in the condenser and is likely to cause leaks.

If, as is usual, the machine has atmospheric exhaust openings, they can be piped to the condenser through a gate valve, the condenser exhaust being blanked off. With this arrangement any desired back pressure may be held on the turbine, while the condenser is working under a high vacuum. The condenser is kept cool and there is no danger of damaging it or the air pump. The readings are the same as for the load curve. The load should be gradually increased until the last valve is practically wide open. If too much load is applied, the speed will fall off when the last valve is wide open.

A bowl pressure curve is generally taken at full load, with the governor operating. The range of initial pressures should be as large as possible, in order to neutralize the effect of throttling on any of the valves. All readings are taken in the same manner as for a load curve.

A superheat curve is generally taken at two points, though more may be taken, one at low and the other at high superheat. The conditions and readings are the same as for the load curve, with which it may often be combined to advantage.

A shell pressure curve is taken on those turbines that are equipped with stage valves, or with a movable diaphragm between stages.

This can generally be combined with the load curve. The group of nozzles controlled by the stage valve should always be wide open or closed tightly. They should never be throttled, as this will invariably increase the water rate.

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MINING LOCOMOTIVES

The preliminary tests taken on Mining Locomotives consist of the measurement of grid resistances, checking controller wiring and checking up the parts with the Engineering Notice.

With the locomotive on the testing stand, the breaker should be set, resistance placed in series with the motor to reduce the current, the reversing lever turned to the series position and the controller handle then turned to the first position. The current should be adjusted to about 10 amperes and the grid voltage drop measured between adjacent fingers on the controller. If the drop does not check within 10 per cent. of that shown on the Standing Instructions for this type of controller and grid, either changes have been made in the grids or they are wrongly connected. The variation should be reported at once.

The locomotive should be operated on all points of the controller, forward and reverse, both series and parallel, in order to check the connections. Note if reversing lever indicates the correct direction of travel. To check the multiple connections the motors should be started in both directions *but since full voltage is impressed and the series motors are running without load the power should be thrown off as quickly as possible.*

With the controller in the full series position, the motors should be given a bearing run for 15 minutes in each direction, after which resistances should again be measured.

The brakes should be tested by setting them and turning the controller until the motors are taking twice the current required for the rated draw bar pull. This current is determined from the characteristic curves of the motors as shown by Technical Report on that motor.

To determine the draw bar pull the locomotive is coupled to a fixed point and the controller turned until the wheels slip, the maximum current and voltage being recorded. By using the characteristic curve of the motors on the locomotive the tractive effort is found corresponding to the maximum current desired. Then the draw bar pull of the locomotive $T = T_1 \times \frac{R_1}{R} \times \frac{D}{D_1}$

Where R_1 = Gear ratio from characteristic curves

D = Diameter of wheels from characteristic curves

T_1 = Tractive effort from characteristic curves

R_1 = Gear ratio of motors of the locomotive

D_1 = Diameter of wheels on the locomotive.

The value of the tractive effort should, of course, be corrected for any variation in voltage of the locomotive from that used in the characteristic curve.

Locomotives having chain-driven cable reels should be tested for reel operation as follows: About 150 ft. of cable should be unwound, the terminal connected to the power circuit

and the locomotive operated until the length of cable is wound on the reel. This procedure should be repeated several times for each position of the shifting lever.

Locomotives equipped with motor-driven cable reels should have a torque test made on the motor with lever and spring balance at specified current inputs for different voltages. Resistance should be measured of the motor and its rheostat, and the reel should be operated a sufficient length of time to ascertain whether the clearances and connections are satisfactory and the bearings in good condition.

All questions on the Testing Record must be intelligently answered and any other data recorded that will assist in determining results from the test.

Cable reels should receive individual high potential tests. The locomotive should be tested with high potential by applying a high potential to the trolley in position.

TRAIN CONTROL APPARATUS

Inspection and High Potential Tests

Before testing any apparatus, a careful inspection must be made for any mechanical defects. Any part of apparatus that will be subjected to a difference of potential, must be given a high potential test, corresponding to that specified in the engineering briefs.

AIR BRAKE APPARATUS

This includes valves, governors, strainers, cylinders, and all other parts that make up the braking system of a car or train.

Valves

Air valves are manufactured under the following type letters: A, S, VL, E, and TE.

The A and S are motorman's valves, different forms of which are used for straight air and emergency brake systems.

The VL is a pressure reducing valve used for automatic air brake systems, and reduces the main air reservoir pressure to a lower and constant pressure.

Type E includes all emergency valves. One of the most important is the Form E, used with automatic air brake systems in connection with the pilot valve located in the controller. It exhausts the train pipe whenever the pilot valve is open, thus applying the brakes to the car or train.

Magnet valves are included under the Type TE. They are used for remote control. The Form B is used for operating pantagraph trolleys.

Mechanical Inspection

Each valve is given a careful inspection to see that all the pipe connections have good threads. In the Types A and S, the fit of the handle should not be too loose. There should be only enough clearance to allow it to be easily removed. The handle should move over the different positions with comparative ease and be removable only in the lap position.

Air Valve Tests

Every casting, which will be subjected to air pressure in service, should be tested for porosity. This is done by immersing the casting under pressure in water. Where this cannot be done, cover the casting, under air pressure, with soap suds. Water must be used in every case to determine the amount of leakage, and all castings showing a continuous leakage must be rejected.

After assembly, each valve should be subjected to an air pressure and operated as near as possible at the service pressure. All parts should then be again tested for leaks by immersing

in water or by covering the part with soap suds, while under pressure.

Valves with metal stem seats are provided with ground stems   The stem and hood are inspected before being assembled on the valve body.

Governors

Governors automatically keep the air pressure of the braking system within a certain range by opening and closing the compressor motor circuit.

Operating Test

Each governor is stamped with type letters and numbers; the letters represent the style of the governor, and the numbers represent the capacity and range at which it will operate. The first number indicates the minimum opening pressure in pounds per square inch. The second number denotes the maximum opening pressure. The third denotes the variation in the opening and closing pressures. The tests are similar in all governors and consist of connecting them to a source of compressed air, the compressor motor circuit being wired through the governor tested. The governor should then be adjusted to open the circuit at the minimum opening pressure and close it as soon as the pressure is reduced by an amount equal to the given pressure range. It must then be tested for maximum opening pressure and should again close when the pressure is varied through the amount equal to the normal range.

All parts under pressure should be examined for leaks.

Type ME 65–100–10 Form A Governor

This governor is designed for use with a large compressor, the circuit of which is made or broken by a contactor or contactors controlled by the governor. The test is similar to that given above, except that the main circuit of the compressor is broken by the contactors controlled by the governor instead of by the governor direct.

Strainers

Strainers are used in air brake systems to catch scale and small particles that would interfere with the operation of any of the apparatus. They are tested with air pressure and examined for leaks.

CONTROLLERS

The R, K, C and T controllers comprise the principal types. All others are modifications of the above

The R and K types make and break the main motor circuit within the controller.

The Type C controller makes and breaks a circuit which operates contactors that open and close the motor circuits. With a contactor box on each car and the control circuits

connected in parallel, the motor circuits for a whole train can be controlled with one controller.

Type T is used with induction motors, generally being used to cut out resistance in the rotor circuit of Type M motors.

Inspection

The development of each cylinder and its fingers should be examined to see that they check with the DS diagram. The fingers should make good contact on the segments of the cylinder and in the order shown. Controllers having several auxiliary fingers in series should be tested to see that these fingers make and break contact simultaneously. All auxiliary release knobs should open the auxiliary contact fingers when released at any position of the handle. The main cylinder and reversing cylinder should interlock, so that the reversing handle cannot be thrown when the controller is in any but the off position. When the reversing handle is in the removable position, the main cylinder should be locked in the off position. All controllers should receive a careful inspection for mechanical defects. All cables passing through the frame of the controller should pass through an insulating bushing. There should be sufficient clearance between points at different potentials and between all current carrying parts and frame.

Operating Test

All controllers should be connected and operated under service conditions as nearly as possible. Those controllers which operate the main motor circuit should be connected and operated with a motor or motors with the proper resistance in circuit, to check the wiring and the blow-outs on the different fingers. Carefully note whether the arc blows in the proper direction and ruptures satisfactorily when turning the controller to the off position. When the controller is not adapted to motors used in the testing department, the complete development and wiring of the controller should be carefully checked with the DS diagram. Those built to operate contactors should be connected to the latter and operated, noting the direction the arc blows as in other controllers.

When turning the controller to the on position, the auxiliary finger or fingers should make contact first, and break last when turning to the off position. Where a separate blow-out is used for the auxiliary fingers, it should be carefully tested. The auxiliary fingers, whether fitted with a blow-out coil or not, should break the total current of the controller in any position, when the auxiliary release knob is released.

Automatic and Semi-Automatic Controllers

Several types of the C controllers have their cylinders fitted with a spring and governor so that when the handle of the controller is turned to the full on position, the spring is wound up sufficiently to rotate the cylinder. The governor should be adjusted so that the cylinder will rotate in the specified time. The governor is fitted with a small magnet coil which

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should lock and hold the cylinder in any position when the specified current is passed through the coil.

PILOT VALVES

Many C controllers are fitted with pilot valves operated by the auxiliary release knob. This pilot operates a valve for an emergency operation of the brakes. They should be connected to an emergency valve which should trip whenever the auxiliary release knob is released. The reversing handle should interlock with the valve in the off position, and should prevent tripping of the emergency valve. The valve should operate quickly without leakage when closed.

REVERSERS

Reversers used in Type M control are operated by solenoids energized through the reversing handle of the controller. The segments on the rocker are so arranged that a movement from one extreme position to the other changes connections and reverses the armature circuit of the motor.

Operating Test

The operating test consists of connecting the inductive resistance specified between the first and third fingers, one side of the shop to the third finger, with the other side connected alternately to the two solenoid coils. Under these conditions the reverser should operate quickly and throw completely over, without rebounding. It should be operated on the different voltages specified. The arc formed on the control fingers must be blown outward from the fingers and should rupture immediately. This should be noted. The coil resistances should be measured and should check within 10 per cent. of that specified in the engineering briefs.

Spools for Supply Shipments

After the high potential test, the resistance of each spool should be measured and should check within 8 per cent. either way, from that specified in the engineering briefs.

MS SWITCHES

MS switches are used both in the main and control circuits. They are provided with a quick break mechanism, and generally with a magnetic blow-out.

Each switch should be examined for mechanical defects such as broken or loose parts. The switch should work freely and should not stick or bind in any position. It should make good contact when closed.

Those switches designed to open the main current are given a blow-out test, which consists of breaking a specified current with the switch, in order to see that the arc is blown outward, and ruptures satisfactorily.

CUT-OUTS

Cut-outs for train control service are used to cut out the control circuits of individual cars from the rest of the train, one cut-out being placed on each car.

Besides seeing that the fingers make good contact on the contact segments, all fuses should be "rung out" to see that they are in good condition.

CONNECTION BOXES

Connection boxes are used as splicing junctions where the wiring of the car is run through conduit. They consist of a metal box containing connection terminals to which wires may be easily connected or disconnected. They receive a high potential test only.

MV TRIPPING SWITCHES

These switches consist of a series coil through which the motor circuit is wired, and a small control switch through which the control circuit for the line contactors is wired.

The series coil operates an armature fitted with a calibrated spring similar to a circuit breaker, so that if an excess of current is taken by the motors, the armature trips out the control circuit switch, opening the contactors in the motor circuit. Examine the compound box to see that it is not cracked or broken, and that all flat headed screws are center punched other than the removable screws used in fastening the cables.

The control switch should work freely and make good contact when closed.

The switch should open when the lever is thrown to the off position.

All MV switches are calibrated for three tripping points. (See Engineering Briefs.) They are sent to the test for calibration without the cover. The armature should be held in the operating position by means of a block of fibre or other non-magnetic substance, *viz.*: as though it rested against the cover. Marks are made to determine the relative positions of the cap of the calibrating springs for the different currents. The switches are then returned to the shop for stamping and assembly of cover, after which they are given a blow-out test, which consists of breaking a small inductive circuit with the switch to determine the direction of the blow-out.

CONTACTORS

Contactors are used for making and breaking the motor circuits on a car. They are operated by a solenoid fitted with a plunger which actuates a lever carrying one contact tip, the other tip is stationary, and fitted with a blow-out coil which helps to break the arc between the tips.

There are two distinct types of contactors: DB contactors which are used for direct current work, and DBA contactors which are used for alternating current work.

The DBA contactors have a laminated armature and an E shaped laminated field with copper shading coils in the face of the outside leg, to prevent humming when the contactor is closed.

The different types are divided into groups or sizes which have different ratings. The type number refers to the rating. The form letter denotes the style of interlocks or other mechanical parts, and the form number the number of the spool that should be used on the contactor.

Inspection

Each contactor should be examined carefully for mechanical defects, such as broken arc chutes, cotter pins, loose screws or bolts. Also note whether it bears the Mechanical Inspection Department's stamp. The contact tips when closed should make good contact over their full width. The copper shunt should be free from sharp kinks or bends and should not rub on any metal part having sharp or rough edges. When the contactor is open the springs should have sufficient tension or compression to hold them in their proper place. All contactors must operate freely, and must not stick or bind in any position.

Operation Test—Type DB
Commercial Tests

From the tables given in the engineering briefs, see that the specification on the spool corresponds with the stamping on the name plate.

When hung in the proper position, the contactor should pick up and wipe contact at or below the current values given for the respective spools, care being taken that the contactor wipes full contact, as sometimes the pick up current is taken to be the same as that required for the wipe contact. To avoid this error, note that the first upward movement of the plunger only brings the contact tips together. This is called the pick up. The next movement wipes the contacts over one another, and also increases the pressure between them. The amount of this movement should equal or exceed that given in the Engineering Brief.

Measurement of Spring Pressure

Insert a strip of paper or cloth between the tips, and put enough current through the operating coil to fully close the contactor.

Hang a spring balance from the screw heads holding the tip on the finger, and note the pull required on the spring balance to loosen the paper between the tips.

Resistance Measurement of Spools

The resistance of each coil is measured by taking a pressure drop measurement. It should be within 8 per cent. above or below the specified resistance.

Operation Test—Type DBA

The pick up and wipe is similar to that in the DB contactors. As each DBA contactor, however, is connected directly across the line, it is tested for the operating voltage instead of the current. The voltage should be obtained by gradually raising the field on the alternator.

The magnetizing current is measured at the proper frequency, and should be taken with the armature fully closed.

The finger pressure should be taken as in the DB type, with the exception that the spring balance is fastened to the upper contact tip by a V shaped bar, one end of which slips under the screw heads, allowing the pull to act at right angles to the contact tips. See that the contactor wipes on the same voltage at which it picks up. It should do so, to protect the tips from freezing (welding together) due to insufficient contact area. The operating coil would also burn out, since with A.C. contactors the current is high until the contactor is closed. After the contactor has wiped, it should be perfectly noiseless.

SPECIAL TESTS

Contactor

The test sheet should contain the following data:

Coil specification (No. of turns and size of wire). Cold resistance and temperature of coil at which the cold resistance is taken. Number of coils in series or multiple during test.

Finger Pressure

This test is made by holding the contact fingers at full wipe position, attaching a spring balance to the screw which holds the finger to the jaw by means of a small loop of wire. A pull is then exerted through the spring balance until the fingers separate sufficiently to allow a thin strip of paper, placed between them, to be drawn out. The pull as recorded by the spring balance is taken as the finger pressure. The pressure of each finger should be measured separately.

With A.C. contactors in which the upper instead of the lower jaw is movable, one end of a small lever is fastened to the finger instead of the balance. With the balance placed on the other end of the arm and with the fulcrum in the center, the finger pressure can be obtained in the manner just given.

Minimum Pick Up and Wipe

A contactor is at "pick up" position, when the armature is raised so that the fingers just make contact. At "wipe" position the contactor is fully closed.

On D.C. contactors the amperes, and on A.C. contactors the volts are read. In either case the terminal voltage must be just sufficient to pick up and wipe the contactor contacts, when switched in circuit.

The "wipe" voltage sometimes is different from the "pick up" voltage. In such cases both values should be recorded. To determine the wipe voltage, lift the armature mechanically to the "pick up" position before closing the switch.

On A.C. contactors, two additional tests, regulation of alternator, and chattering and drop out voltage, are made in connection with the minimum pick up test.

Regulation of Alternator

With the armature blocked open, read the speed and voltage of the alternator both with and without the contactor in circuit. Repeat with the contactor blocked shut.

Chattering and Dropout Voltage

With the contactor picked up and fully wiped, note the minimum to which the voltage can be reduced before the contactor becomes noisy, and also note the voltage at which the contactor opens.

Saturation Curve

This curve is taken by reading volts, and watts if required, for different values of current with the contactor held open, closed, or at such air gaps as the special instructions may give.

Pull Curves on D.C. Contactors

This curve is taken by holding a constant current and reading the pounds pull for different air gaps. The curve is taken in either of the following ways:

First: By carefully adjusting the air gap, weighting down the plunger, and holding the amperes constant while weights are subtracted from the plunger until it picks up.

Second: By weighting down the plunger and holding the amperes constant, while the air gap is gradually decreased until the plunger picks up. The air gap is then measured. A variation of this curve is sometimes made by holding a constant air gap and varying the amperes and weights. In connection with the data for these curves, the length, diameter and weight on plunger should be given; the length of plunger being taken as the length from the butt end to the center of the hole in the lower end.

Pull Curves on A.C. Contactors

The method of taking a pull curve on an A.C. contactor is more complex than on a D.C. contactor. In either case the pounds pull is dependent upon the ampere turns. In a D.C. contactor, however, the amperes at any voltage varies directly with the resistance of the coil and is independent of the plunger air gap, whereas in an A.C. contactor the amperes at any voltage

does not vary with the resistance, but with the impedance. The reactance varies with the armature air gap. For this reason it is not desirable to hold the amperes constant. If, however, the voltage is held constant, an error will be caused due to the resistance of the coil being increased by heating.

In tests where great accuracy is required, this error can be eliminated and all contactors can be compared upon a common basis by the following method:

First: Measure the resistance of the coil cold.

Second: Holding the voltage constant at that value at which the pull curve is desired, take an ampere air gap curve; i.e., read amperes at various air gaps. This curve should be taken as rapidly as possible to avoid undue heating of the coil.

Third: Take a check reading of the resistance to see if the coil has been much heated. If the heating is slight, an average of the two readings should be taken as the resistance of the coil.

Fourth: The ampere air gap curve thus obtained should be corrected for a temperature of 25° C. and replotted.

Fifth: Take a pull curve as given by the first method for D.C. contactors, holding the amperes constant corresponding to the different air gaps as obtained from the corrected ampere air gap curve.

In cases where the cold temperature of the coil happens to be within a few degrees of 25° C. the pull curve can be taken directly, holding the voltage at the value at which the curve is desired. Great care should be taken to prevent undue heating of the coil. The current must be on only for a sufficient time to obtain readings. At the completion of the test take another check reading of the resistance to determine the heating.

Work Curve

This curve is taken by measuring the pounds pull necessary to lift the plunger or armature at different air gaps, having the complete operating mechanism of the contactor and spring adjusted to give the finger pressure required.

Speed Curve

Speed curves are taken on contactors and relays to determine the time a contactor takes to close or to open.

For taking this curve, a special mechanism has been made which operates as follows: The contactor is set on a special stand and a mechanism is then fitted to the plunger of the contactor so that a pencil attachment operates along a vertical line. The pencil bears upon a sheet of sensitive paper which is secured to a cylindrical drum, revolving about a vertical axis. The drum is rotated by a small shunt motor operating at a constant and uniform speed. Upon the periphery of the drum contact fingers are fastened, which make and break the circuit through the contactor coil at definite movements. The contactor is then operated through a number of cycles, and the mean curve is drawn. In this test the required voltage

must be held across the coil without resistance in series, on account of the inductance of the circuit.

Heat Runs

This test is very similar to the heat runs made on other apparatus and consists in measuring the temperature of the coil or other part at frequent intervals, both by thermometer and resistance. It should be noted that, as the operating coils are well wrapped with twine or other binding, thermometers placed on the outside of the coils do not give a fair indication of the temperature of the interior of the coil. For this reason the temperature must be calculated from the rise of resistance. To get these readings as accurate as possible, care should be taken in measuring the cold resistance. All heat runs on coils should be made with coils assembled in the contactor frame, unless otherwise specified.

Life Tests

Life tests on contactors are made generally to determine the effect of service on the wearing qualities of the various parts. Before starting the test, the diameter of the hinge pins and hinge pin bearings, the maximum air gap, finger pressure, and all other parts of the contactor that will be affected by service, should be carefully measured. During the test a daily record should be kept of the number of operations, and of the operating failures of any of the parts. At the completion of the test, the parts measured at the beginning must be again measured to determine the amount of wear.

FUSE BOXES

Commercial Tests

Fuse boxes are made of fibre or compound, and are fitted with terminal blocks, in which ribbon fuses may be readily placed.

The principal test is high potential, for the value of which see Engineering Briefs.

Fuse Boxes With Magnetic Blowout

After the high potential test, a small fuse is placed across the terminal of these boxes. A current is then passed of sufficient capacity, and at sufficient voltage, to blow the fuse immediately. This is done to determine the direction of the blowout.

FUSES—SPECIAL TEST

The test sheet should contain the catalogue number, ampere rating and dimensions of the fuse, also the style of box or holder in which the tests were made.

Before starting the test, carefully inspect the fuses for defects, such as sharp bends, dents, burred holes, etc., discard-

ing those that are not perfect, unless the test is being made to get an average curve on fuses from stock.

Test to Determine Rating

Connect a switch to the fuse box or holder, using a short circuiting switch in multiple with both. If run off the shop circuit connect a water box in series. If run from the "booster," the current can be controlled from the booster field with a low resistance grid in series with the booster armature.

With the series switch open, and the short-circuiting switch closed, adjust the current to the desired value, and hold as near constant as possible. Then close the series switch quickly and open the short-circuiting switch, and note the time it takes before the fuse blows by a stop watch. Test at least ten fuses at current values which blow them in from 2 to 4 min. Fuses are rated to blow in 3 min. at 33⅓ per cent. overload. When a number of fuses are blown, the holder is likely to get very hot unless care is taken to cool it between tests. Thermometers should generally be placed on the fuse holder and the temperature kept below 75° C.

Time-Current Curve

This test differs from the last only in the time taken to blow. The fuses should be blown at the current values which blow them in 10 seconds up to 3 minutes.

COUPLERS

In train-control work, couplers are used to make temporary connections for the bus line, and control circuits between the cars of a train. Two parts are included in the complete coupling; the socket coupler, Type DA, and plug coupler, Type DC, which fits into the socket coupler.

The contact terminals should be well fastened in the compound base, and the cover on the DA coupler should be held firmly closed by the spring.

Couplers without cables are simply given a high-potential test, from the frame to each terminal, and between each terminal and the adjacent terminal.

Sockets are placed at the ends of the car and cables run from them to the connection boxes in the car. When the socket is assembled with a cable, it is given the usual high potential test, and then each terminal is rung out with a lamp circuit to see that it is connected to the proper cable wire.

CONTACTOR BOXES

In the Type M or C control, instead of breaking the motor circuits in the controller, as is done in the K control, the controller operates a set of contactors assembled in a contactor box, which open and close the motor circuits. One contactor box is placed on each car, and the control circuits, besides being brought to the controllers of the car, are taken to couplers

at either end of the car, from whence they can be connected by jumpers to other cars, and operated in multiple with them. The whole train is thus controlled from one controller. This control is manufactured either automatic or non-automatic.

In non-automatic equipments, the motorman has full control of the acceleration of the car. In the automatic equipments, however, he does not control the resistance (acceleration) points. The automatic feature can readily be connected. One end of the cable is left open which can be afterwards connected to the connection boxes. The different wires are designated by various colors. For the colors and numbers corresponding see DS diagram.

Inspection

The stamping on each interlock should be carefully checked to see that it corresponds with the interlock itself, and the DS diagram. The terminal board and the terminals on all wires should be clearly and properly stamped and all wiring neatly done. The interlock rods should clear the back frame of the box by at least $\frac{1}{4}$ in. The name plate on each contactor and on the contactor box itself should be checked.

Operation Test

Each contactor box is connected to a controller and reverser, and operated so as to test all the control circuits. The main or motor circuits are rung out according to the DS diagram. The operating voltage for each set of equipments should be obtained from engineering instructions. The contactors should pick up and fully wipe on the minimum voltage, in the order specified. During an operation test, see that the blow-out on the interlock of the bridge contactor blows the arc downward and properly ruptures it at the maximum voltage.

The circuit breaker control wires, if any, should be connected through a closed interlock which opens on the first step.

Potential Relay

All automatic equipments having a potential relay should operate at a voltage higher than that at which the relay picks up. The relay should pick up at or below the minimum voltage specified.

JUMPERS

A jumper consists of two coupler plugs connected by a cable. It completes the circuits between cars.

After the high-potential test, jumpers are "rung out" to see that the correct connections exist between the plugs.

CIRCUIT BREAKERS

There are two different types of railway circuit breakers, the IB and MR, most of which have brush contacts. The

main circuit current is carried by a brush, which is protected from the arc when opening current by the auxiliary fingers.

The MR circuit breaker is closed manually by throwing the handle to the on position, and may be tripped by throwing the handle to the off position, thus operating as a quick-break switch. It is also arranged to trip out automatically on overloads.

The DB circuit breakers are used in the Type M control. They are provided with solenoids, for opening and closing, which are energized through a switch in the motorman's cab, the breakers themselves being under the car.

Inspection

All the cable terminals should be well fastened in the terminal blocks to prevent being lost in transportation. The arcing or secondary fingers should remain in contact, when opening the circuit breaker, after the brush has opened contact by at least $\frac{1}{4}$ in. Both brushes and secondary fingers should make contact over their full width. All auxiliary switches on the circuit breaker should be examined to see that they make good contact at the proper time. The copper strips composing the shunt should be free from kinks or sharp bends.

Calibration

Each circuit breaker is calibrated for three tripping points. It is first tested for low tripping point, then for high point and finally for the intermediate point. It is left at the latter point, and the check nut is then set. Marks must be made designating the relative position of the cap of the calibrating spring for the different currents.

Blow-Out Test

Each circuit breaker is given a blow-out test in order to determine the direction of the arc.

RELAYS

Railway relays can generally be classed under three heads: Current relays, potential and transfer relays.

Current relays comprise all those which have their operating coil in series with the circuit in which the current is to be controlled; the controlling circuits being wired through its contacts and discs.

Potential Relays

Potential relays comprise those which have their operating coil wired across the operating circuit, thus depending on the voltage for operation. They are used where a certain value of voltage is required for proper operation. The controlling circuits of the apparatus are in series with the studs and discs, which are always open unless the voltage is sufficient to operate the apparatus.

Transfer Relays

Transfer relays are used for transferring control circuits from one apparatus to another, or to make different connections on the same apparatus.

Operating Test

The relay should be able to break the specified amount of current on the contact studs, and if provided with a blow-out the arc should blow in the proper direction.

The operating coil should operate the relay under the conditions specified in the engineering instructions. The discs should make good contact on the studs, and the wiring should be arranged in workmanlike fashion to prevent electrical or mechanical breakdowns in operation.

DIRECT CURRENT RAILWAY SIGNALS

The following is intended to explain the principle upon which automatic block signals operate, and to outline the requirements of the different pieces of electrical signal apparatus manufactured by this Company.

Referring to Fig. 151, if a car or train occupies the track between the insulated joints *J.J.* it shunts the relay *R*. This allows the armature to drop, opering the local signal circuit, which, when energized, holds the signal in the clear position as shown. With the signal circuit opened at the relay, the arm is returned to "danger" by the counterweight of the semaphore spectacle. This arrangement is known as the "Normal Clear" system.

Signals are also operated on the "Normal Danger" plan but the circuits are more complicated than with the "Normal Clear," although the design of the apparatus is practically the same.
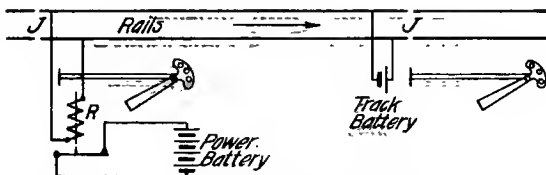
Fig. 151

ARRANGEMENTS OF TRACK CIRCUIT AND CONNECTION FOR NORMAL CLEAR AUTOMATIC BLOCK SIGNALS

With the normal danger, the arm stands at "danger" until a train is about three thousand (3000) feet from the signal, when, the block being unoccupied, it will assume the "Clear" position and so remain until the engine has passed. The arm will then return to "danger," and so remain until the above operation is repeated.

Signals are made in three forms, namely: The Lower Quadrant Two Position, in which the semaphore blade moves in a downward direction through a predetermined angle varying from 60° to 90° from the horizontal or stop position; the Lower Quadrant Three Position, in which the arm moves downward to the 45° position ("caution" indication), and from 45° to the 90° position giving a "clear" indication; and the Upper Quadrant Three Position in which the arm moves upward instead of downward from the stop position.

With reference to the term "Caution Position" in a three position signal, it might be well to explain that the signal circuits are so connected that when a train passes out of a

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block, the signal at its entrance will assume the "caution" position, and when the train has passed out of the second block it will assume the 90° or "clear" position. This applies to both Upper or Lower Quadrant Three Position Signals, operating on the "Normal Clear" plan.

INSTALLATION OF SIGNAL MECHANISMS

The mechanism is located either at the base of the mast (Bottom Mast Type) or at the top (Top Mast Type).
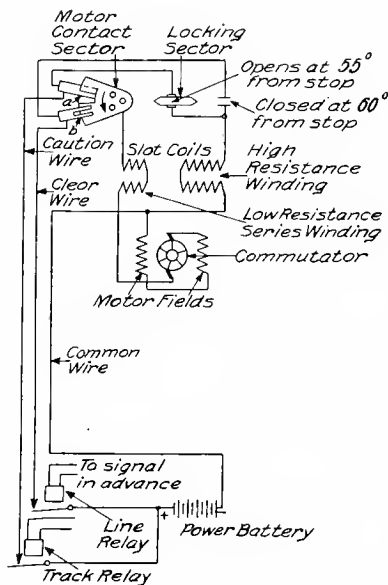
Fig. 152
CONNECTIONS OF M-114 RAILWAY SIGNAL

In the bottom mast type, the signal mast is supplied with a Semaphore Bearing, supporting a spindle upon which the Semaphore Spectacle is mounted, and the signal is either pushed "clear" by an up-and-down rod of ¾ in. pipe or pulled clear by a cable with suitable connections to the motor.

In the top mast type the Semaphore Spectacle is mounted on the main shaft of the mechanism and is forced to clear when this shaft is rotated by the driving motor.

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Auxiliaries

Besides the signal proper with its painted blades for day indication and colored lights for night, there are many pieces of auxiliary apparatus used in connection therewith.

The Switch Indicator is installed at a track switch and is so connected that it will repeat the indication of the signal protecting the block.

The Switch Box (or Switch Circuit Controller) is attached to the switch point and equipped with contacts that will shunt the track battery or open the signal circuit (frequently both), thus throwing the protecting signals to danger when the switch is open.
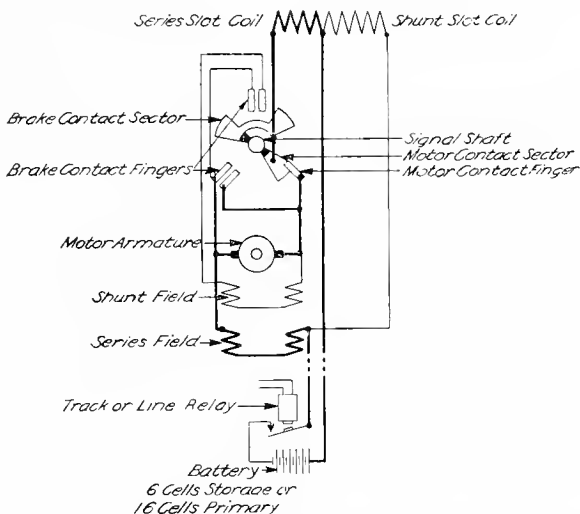
Fig. 153
CIRCUITS OF M-113 RAILWAY SIGNAL

The Tower Indicator (or repeater) is located in the signal tower and so connected as to repeat the indication of a certain signal for the information of the operator.

The track and line relays are used to open and close the signal and auxiliary circuits. These and many other devices are required for the safe operation of trains controlled by Automatic Signals, and a brief description of each is given under its respective heading.

D.C. SIGNAL MECHANISMS

The construction and operation of the signal mechanism is the same in both the Top and Bottom Mast Types, the only

difference being in the mechanism case, external connections and method of installation.

A complete signal mechanism consists of a water proof case in which are contained a motor suitably mounted and connected to the main driving or clutch wheel through a train of gears, a "slot arm" mounted on the main shaft and carrying the slot magnet and levers, a circuit controller and a liquid dashpot or buffer, actuated by the main shaft.

The bottom mast case is supplied with a lug and bolts for attachment to the pedestal and the top mast with suitable sockets for mounting on the mast.

EXTRA CIRCUIT CONTROL

In addition to the necessary contacts for clearing the signal, each mechanism is equipped with a number of extra circuit closers used for interlocking the circuits of different signals; for example, the control circuit of two signals might interlock so that Signal No. 1 could not clear until No. 2 had assumed the "danger" position.

SLOT ARM

The slot arm carries the necessary levers and slot coils that, when energized, hold the levers in engagement with the pins of the clutch wheel. It is mounted on a square section of the main shaft and forces the signal arm to clear when the clutch wheel is driven by the motor. With the coils de-energized and the armature released, the slot arm is returned to the "danger" position by the main shaft and the Semaphore Spectacle.

DASHPOT

The dashpot or buffer, located at the back of the case, consists of a cylinder, piston with check valve and rod, and suitable connections for attachment to the signal case. The lower portion is in the form of a ring and the necessary movement of the piston in the cylinder is obtained by the rotation of an eccentric fixed to the main shaft, within this ring.

The eccentric is so located on the main shaft that the maximum effect is reached when the arm approaches the stop position.

OPERATION OF THREE POSITION SIGNAL

With the arm at danger (horizontal position) connections are made between the power battery and signal in accordance with diagram, Fig. 152.

With the connections made in this manner, when the track relay is closed current will flow from the battery to the motor sector, series and shunt winding of slot coil (the two running in multiple while clearing), to motor and through common wire to battery. This moves the signal arm from "danger" to "caution," breaks the motor circuit at "a," and the low resistance series coils of slot magnet are cut out, leaving only the high resistance lock or slot coils (usually 500 to 1000 ohms) in

the circuit. When the line relay is closed, the above operation will be repeated, except that the motor circuit will be broken at "b" with the arm in the "clear" or vertical position. This applies to either Upper or Lower Quadrant Signals.

OPERATION OF TWO POSITION SIGNAL

The principle of this signal is practically the same as that of the three position type, except that only two wires are required for its operation, the connection being made as shown in Fig. 153.
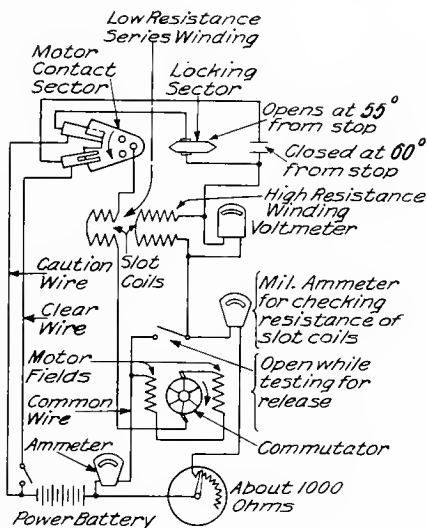
Fig. 154
DIAGRAM FOR TESTING D.C. SIGNAL MECHANISM

Inspection

Before testing, the signal mechanism must be well lubricated and given about 1000 complete movements to see that all parts are in good working condition. The mechanism should be inspected to see that all parts are clean, that the control fingers are making proper contact with the sectors, that the motor brake is in good working order with proper air gap and ample friction surface. The brush-holders must be free on the studs and the brushes must make good contact on the commutator, which should be slightly oiled. See that no metal chips or fillings adhere to any part of the mechanism; also,

that the insulation is free from aluminum paint, which is a conductor; also see that the proper air gap is maintained between the armature and pole pieces of the slot magnet.

Connections should be made in accordance with diagram, Fig. 154.
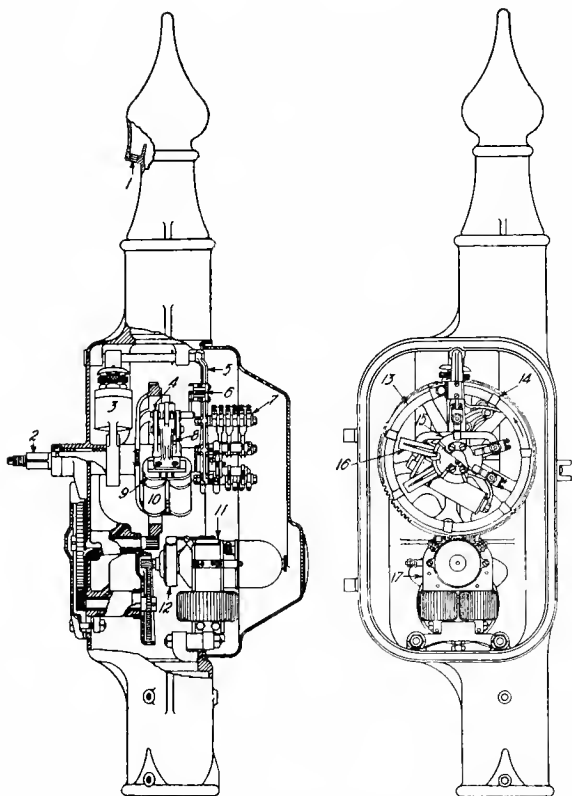
Fig. 155
TYPE M-114 G.E. TOP MAST SIGNAL

Test

The arm should return from clear to danger in about 4 seconds after the release of the lock armature. The current to operate at 60° signal is about two amperes at 10 volts, and

the time from danger to clear about 7 seconds, when the torque of semaphore spectacle is about 30 foot pounds.

This torque, exerted by the counterweight tends to force the signal arm to the danger position when the slot coils are de-energized and the lock armature released. A signal should clear and lock (hold clear) with about 6 volts when the resistance of the slot coil does not exceed 600 ohms, and with about 7 volts when the resistance does not exceed 1000 ohms. After having seen that the signal clears, locks, and returns to danger position in the prescribed manner, the voltage across the slot coils should be reduced by cutting in resistance until a release point is reached.

This point should be carefully noted and in no case should it be less than called for in the Engineering Instructions, as it represents the factor of safety in the signal mechanism; for should the armature hold until the e.m.f. is reduced to, say, one volt, the counterweight would be very little if any more than sufficient to release the armature.

If the signal requires more than the specified time or current to clear, the trouble can be usually traced either to lack of lubrication, dirt between the terminals of wiring connections, or to undue friction of some part of the mechanism. If the signal fails to lock properly at "caution" or "clear" examine the magnetic circuit to see that the yoke fits the cores properly and that the air gap of the armature is not excessive. If these parts are properly assembled, put a milli-ammeter in the lock circuit, clear the signal by hand, read volts and amperes, and check the resistance to see that none of the coils or external connections are short circuited. Care should be taken not to clear the signal with the milli-ammeter in the operating circuit. See that the split finger makes good contact with motor contact sector before the pawl strikes the pins of the clutch wheel when the signal moves from the clear to caution position. A complete signal mechanism of the top mast type is shown in Fig. 155. (M–114 Signal.)

MOTOR

The motor is series wound, and with no load takes about one ampere at 1200 r.p.m. By reversing the brushes with holders, studs and wiring connections, the motor can be made to rotate in the reverse direction. A friction brake for arresting the movement at caution and clear and also for preventing the gears from running backward after the motor circuit is broken, is attached to the frame and released by a thin flat armature bridging the pole pieces. This brake is applied by a spring. When the motor current is cut off and the brake armature released, the spring forces a shoe against a wheel or drum which is keyed to the armature shaft.

Motor Test

The motors are tested before being assembled in the signal case by joining the armature of two motors together by means

of a flexible coupling, one running as a generator. Referring to Fig. 156: Couple the motor to be tested to the "Generator," close the load switch, adjust the resistance until one ampere flows through the armature at 8 volts, throw switch S, note average of volts and amperes, and calculate efficiency by the input and output method.

Before taking any readings, allow the set to run for a few minutes, see that the armature bearings are free, oil rings rotate on shaft, brush-holder free on studs, and commutator and brushes clean and not sparking.
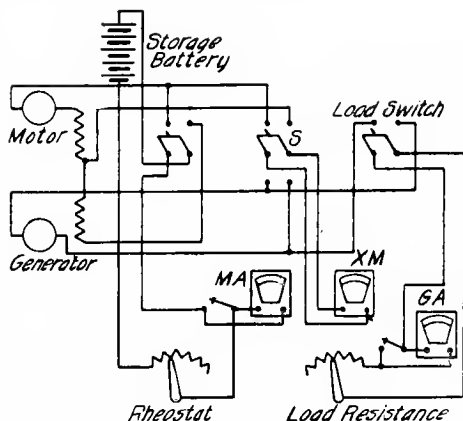
Fig. 156
TESTING DIAGRAM FOR MOTOR

SIGNAL RELAY—D.C. NEUTRAL

This is a Circuit Closing Device consisting of a magnet with cores projecting through the top or terminal board, an armature to which contact fingers are attached for making and breaking the circuit. When the coils are energized, the armature picks up, closing the "front" contact. When de-energized the armature drops away, closing the "back" contacts. All moving parts are enclosed in glass, so that they may be inspected without breaking the seal. (See Fig. 157.)

Track relays (usually 4 ohms to 9 ohms resistance) are installed at each Automatic Signal to open the circuit as shown in Figs. 151 and 152.

Line relays (usually 500 to 1000 ohms) are controlled by the signal in advance, the operating coils being energized by a line running through an extra circuit closer on the signal.

With a three position mechanism, it closes the circuit so as to move the arm from caution to clear.

The track and line relays are of the same type and are identical in construction.
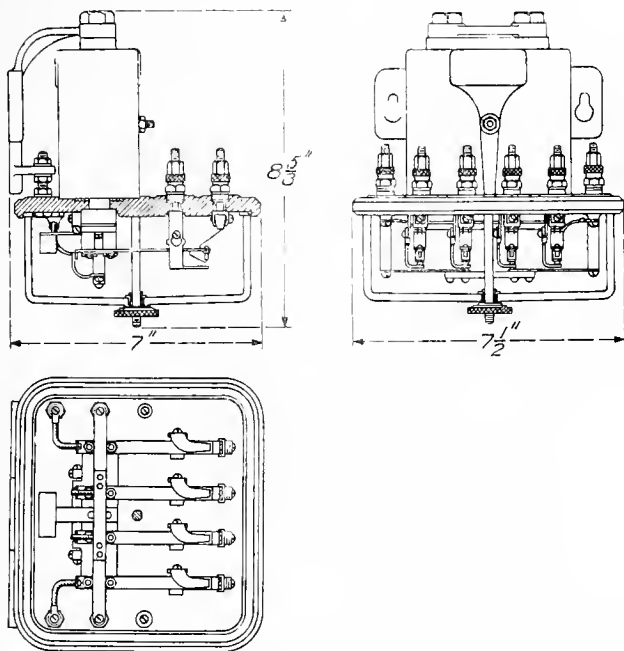
Fig. 157
RELAY

Test

Check Air Gap. See that the armature is running freely in bearings, that the contact fingers are making even contact with the proper break, and that all parts are free from dirt. Mount on the testing stand and connect as shown in diagram, Fig. 158. Send current through the coils, gradually increasing it, until the initial current specified for a given resistance is reached, then decreasing by means of a shunting resistance R, without breaking the circuit, until the armature drops away, and note the current. Then reverse the polarity, again increase to the initial current; then reduce so as to drop away (note the

point). Again increase the current, and reverse the operating circuit, and note the current required to pick up the armature.

With either polarity, it should not pick up with current in excess of that specified for the reverse pick up.

Find the resistance of the contact by running a small current (about one amp.) through the contact points, taking the drop between AA with a portable milli-voltmeter, M.
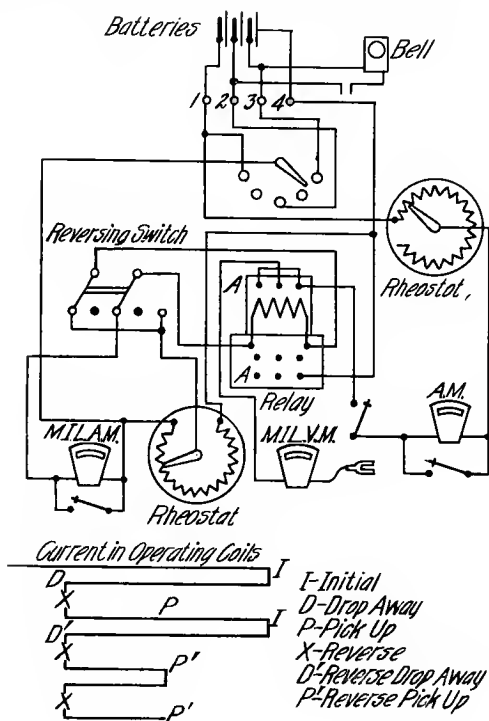
Fig. 158
DIAGRAM OF CONNECTIONS FOR TESTING SIGNAL RELAYS

SWITCH INDICATOR

This is a device which shows whether or not it is safe to move a track switch.

It is usually installed in connection with automatic block signals. It consists of a magnet with armature, to which is attached the necessary levers for clearing the miniature arm when the operating coils are energized. All moving parts are

protected by a weather proof case, having a glass front as shown in Fig. 159. It is mounted on a post near the switch, and the operating coils are energized through a wire circuit which extends two or more blocks and is carried through the front contacts of all the track relays or through the normally closed contacts on the signal mechanism.

A train within the limits of this circuit would make the line open at the relay or signal contacts, releasing the armature and setting the blade at danger. (See Fig. 160.)
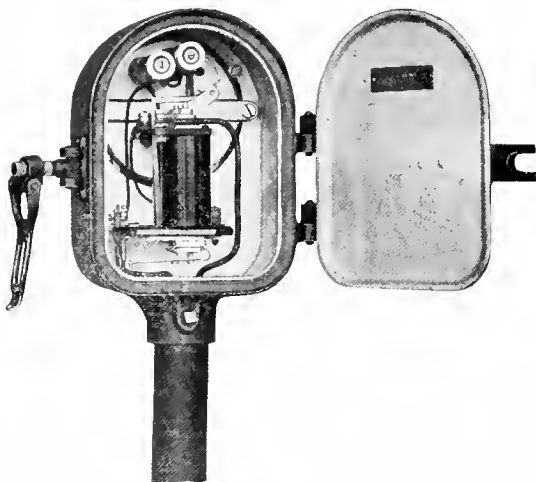
Fig. 159
INTERIOR OF SWITCH INDICATOR SHOWING MECHANISM

The indicators are made to operate in either the Upper or Lower Quadrant.

Some Forms are provided with auxiliary resistances, which are cut in after the indicator is cleared, leaving only sufficient current flowing in the coils to hold the blade at the clear position. This resistance, which is shunted by means of a back contact when the blade goes to the danger position, is usually about twice that of the operating circuit. (See Fig. 161.)

Test

Connect six (6) to ten (10) volts, storage battery, into circuit.

See that the armature picks up (blade clears) with the required voltage, releases (drops away) properly, and that the

Fig. 160
FRONT OF SWITCH INDICATOR

shunt circuit contacts are well adjusted and clean. Check the air gap and see that all wiring connections are tight, and that the blade returns to the horizontal position when the armature is released. Should the blade drop when released, either the mechanical connections are too tight, the counterweight too light, or the contact finger is not properly adjusted. An armature failing to pick up, shows that the shunt contact is poor or the air gap excessive. Put a milli-ammeter in circuit and check the operating and total resistance
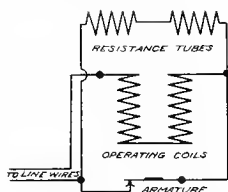
DIAGRAM OF CONNECTIONS
SI-104-A SWITCH INDICATOR
(DANGER POSITION)

Fig. 161

TOWER INDICATOR

This is similar in operation to the Switch Indicator. It is connected to the signal system in the same manner, but installed in the signal tower. It indicates the approach of a train to the operator visually always and sometimes audibly, either by bell or buzzer.

Auxiliary resistance is connected into the operating circuit in the same way as in the Switch Indicator, see Fig. 162, except when equipped with contacts to operate other signal devices, in which case the resistance is omitted. The cover with glass dial can be removed for inspection.

Fig. 162
TOWER INDICATOR

Test

This should be the same as for the Switch Indicator, except for the front contacts with which the Tower Indicator is supplied. When so equipped, the contacts are tested in the same manner as those of DN Relays, the specifications being changed to meet the requirements.

SWITCH BOX

This device is designed to operate by a movement of a switch point, and is usually installed about 3 feet from the track. It is provided with contacts for shunting the track relay when the

switch is opened. Sometimes it is also supplied with a contact for opening a signal circuit, thus throwing the arm to "danger" on one or more signals. Fig. 163.

Test

See that the contacts are clean, and that they open and close the circuits with the proper throw of the operating lever. To check adjustment, connect a circuit through the points and work the operating lever by hand.

MERCURY TIME RELEASE

This is a circuit closing device, consisting of a glass tube containing mercury hermetically sealed, with platinum contact points, projecting through the glass, connected to either side of the case, the two parts being insulated by a fibre disk. One
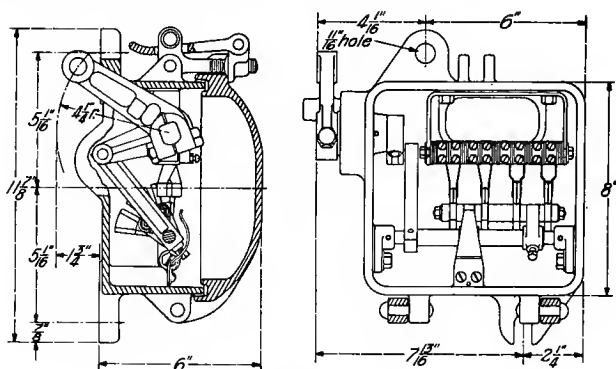
Fig. 163
SWITCH BOX

line terminal is mounted on the support, and the other on the frame, these being also insulated. The glass tube is secured in the case, which is turned to the required angle by means of a rack and pinion. When it is turned in a given direction mercury flows from the large chamber to the smaller one through a small hole, the reverse motion returns the mercury to the large end of the tube.

This device is installed on an interlocking machine in a signal tower. When the latch of the machine is raised, the mercury is thrown away from the contacts, opening the circuit. When returned to the normal position, the mercury flows through the small hole, thus closing the contacts, of which the time can be varied as required. With a release designed to close in 7 seconds, the time can be varied from about 4 to 10 seconds. Fig. 164.

Test

See that the external connections are clean, attach a light circuit to the terminals, throw the release so that the mercury is in the large end of the tube, return the rack quickly to the normal position and note the time interval of closing.
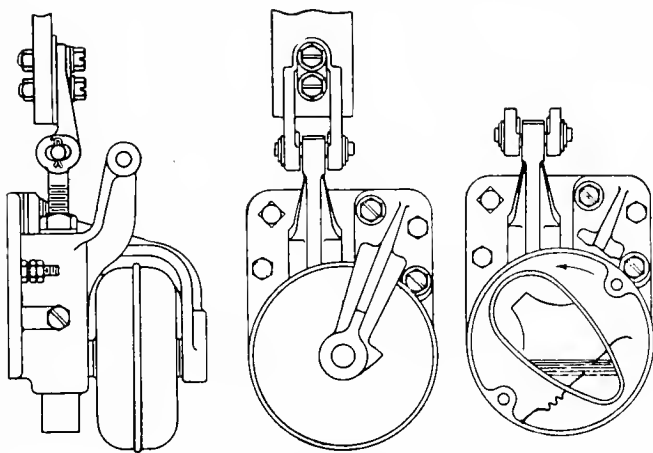
Fig. 164
MERCURY TIME RELEASE

CIRCUIT BREAKERS

Circuit Breakers are built for both A.C. and D.C. work and are made in single-, double- and triple-pole type.

There are two distinct type of breakers, switchboard and railway.

The switchboard breakers are chiefly of the brush type with carbon tipped secondary. They are either hand, or solenoid operated.

The railway type has no carbon secondary but a magnetic blow-out.

All breakers, when delivered to test, must be inspected to see that all screws and nuts, except those used for cable connections, are tight, that no parts are missing, that they operate freely and easily, and that they are positive in action both in closing and opening.

On switchboard breakers, the carbon brush must make and break contact before the main brush.

The main brush must have sufficient spread to insure good contact. The contact can be observed by closing the breaker with a piece of paper between the stud and brush and comparing the impression on the paper. With breaker closed strike the handle several times to see that breaker does not jar out.

Each breaker is tested according to the Engineering Brief. These tests consist of high potential, calibration, and, on new types, heating tests. A blow-out test is also made on breakers which have magnetic blow-outs.

Breakers are calibrated by passing the required currents through them and setting the armature so as to trip at these points. In calibrating a breaker first try for low point and see that the breaker trips readily. Next try for high point. Never mark low point until it is known that the high point can be obtained. The high and low points must lie between the screws which fasten the scale plate. If the high and low points can be obtained as given, continue the calibration by marking the position of the adjusting screws on the scale plate for each value of tripping current. If any trouble is experienced in obtaining either high or low points, the breaker must be blue tagged and returned to shop for changes.

Care must be taken in marking the scale plate. Hold the marker flat on the adjusting screw and make a mark about $\frac{1}{8}$ in. long, beginning at the edge of the plate. This mark must be very distinct as it is the only guide the shop has in stamping the plates permanently.

The breakers must be connected for test in a manner similar to that in which they will be connected when assembled on the switchboard, as the calibration of the breaker is affected by the arrangement of the buses.

In calibrating A.C. breakers the frequency must be correct, as the calibration is affected considerably by it.

A heating test is made on the first few breakers of a new type. These tests are made according to instructions from the engineers.

A blow-out test is made by passing a specified current through the breaker at a specified voltage and then opening the breaker. The arc should blow out instantly and in the proper direction.

Solenoid breakers are not calibrated nor do they have automatic trips unless especially called for, in which case tests are based on engineering instructions. They must receive the same inspection as specified above. When built on requisition, the specification of the operating coils must check with that given on the Engineering Notice. The breaker is then operated at the voltage specified in the Engineering Notice or on the winding specification They must be operated a number of times to see that they are positive both in closing and opening.

They are given a high potential test according to the Engineering Brief.

CIRCUIT BREAKER ATTACHMENTS

A low voltage release, a shunt trip or underload breaker is often required. These are standard attachments and are made up for various voltages and sizes of breakers. Low voltage releases and shunt trips are furnished with resistances. By varying the resistances, the devices are made to operate at the specified voltage.

The tests on these devices are standardized by Engineering Briefs, and consist of testing them for actual operation to meet the specified requirements. They are also tested with the individual resistances to be used with them.

RELAYS

Breaker relays consist of an auxiliary piece of apparatus used in connection with a circuit breaker or oil switch, which is operated directly by the line circuit, closing or opening a· set of contacts in a secondary circuit, which in turn operates the tripping mechanism of the main line breaker or switch.

Relays are made for D.C. and A.C. circuits and are distinguished by types and forms.

Inspection

All relays are subjected to a mechanical inspection before being delivered to test. They should, however, be inspected when received, for missing parts, for good contacts at contact points and for general workmanship and appearance.

Testing

All relays are tested under operating conditions as nearly as possible; that is, the current carrying parts and operating parts of relays themselves are tested to do the work required when installed for service on a switchboard. D.C. relays

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are tested and calibrated at the voltage specified on Engineering Briefs covering standard relays. Series relays are calibrated at the currents corresponding to the coil specification, also all other relays having "transformer windings," "series windings" or "current windings." The coil specifications are generally specified on the Engineering Briefs, but in the case of a special coil, special instructions are issued. A.C. relays are usually designed to operate at 25 to 60 cycles and are so tested unless otherwise ordered. All Time Limit relays are tested with the specified current to see that the time limit device operates properly and gives proper regulation.

Some relays, such as reverse current types, have resistances connected in circuit with them. These are tested with their individual resistances. High potential test is given on all relays between contacts and frame. Relays with series windings are given high potential between contacts and frame, coil and frame, and, as per Engineering Brief, between coils where they are wound for two phases of a circuit.

OIL SWITCH TRIP COILS

Oil switch mechanisms are automatic or non-automatic. Automatic mechanisms have one, two or three trip coils, and require calibration. They are often used in connection with relays as stated in the paragraph on "Relay Testing." Coils are made for "series trip" operation and "transformer" operation. Series coils are tested and calibrated according to specification of coils as covered by the Engineering Brief.

Engineering notices and instructions state what coil is to be used. "Transformer" tripping coils are called for with different calibrated points according to the service to which they are adapted. These calibration points are peculiar to the specifications of the coil and are covered by Engineering Briefs.

ATTACHMENTS

Low voltage release attachments and underload attachments are also adapted to oil switch service, and are tested in a similar manner to those used for circuit breakers.

MISCELLANEOUS HIGH POTENTIAL TESTING

Arc panels, disconnecting switches, lever switches, fuse blocks, expulsion fuse insulators, bus bar supports, trolley shoes, strain insulators and turnbuckles, potential plugs, plug switches for arc panels, wooden rods and wooden parts for oil switches are all given a high potential test as specified in the Engineering Brief.

PORCELAIN INSULATORS

Insulators are of two distinct types; link insulators and bushings.

The Link Insulators are those used for either strain or suspension work and have holes, called cableways, for fastening the cables.

Bushings comprise all other kinds of porcelain insulators which are cylindrical in form, and serve as conduits.

Inspection

Before testing, all insulators should be given a rigid inspection for mechanical defects, such as cracks, flaws, warping, chipping and non-uniformity in color of glaze.

Methods Used in Applying High Potential

In applying high potential to porcelain insulators, they are placed on a rack which holds twelve, and these are tested together.

In the larger type requiring a special test, it will be found advantageous to use two racks at once.

The Link Insulators have cableways on either side between which the potential is applied.

This can be done by using two spiral springs which can be pushed through the cableways and hooked upon themselves, thus making the insulator take the same position as it does in service.

In testing bushings, a pipe or spring is laid through the center of approximately the same size as the hole. A piece of metal foil or spring is then wound around the outside at the middle point. The potential test is then applied between the metal parts.

Routine Potential Tests on Insulators for Switchboard Department

Potential values, where called for, should be determined by the needle gap and striking distance curve C-845. (See Fig. 91.) This determination should be made under testing conditions with the insulators connected to the transformer. (The capacity currents taken by some insulators and the oscillating discharge passing over their surface sometimes seriously affect the transformation ratio.) Where arc over values only are specified, the tester must see that the testing outfit and conditions will not facilitate arc overs.

Insulators in production and not listed below should be called to the attention of the Engineering Department.

Any insulators listed showing serious discrepancies from the results of specified tests, without defects being apparent, should be referred to the Engineering Department before proceeding further.

Tests are called for by letters having the following significance:

"*A*" Apply potential between central stud filling the insulator bore, and the foil band around the outside of insulator. Foil should be so located as to bring the maximum tax (stress) through that section of the insulator which is under maximum stress in service. If the outer surface is not completely glazed foil should be placed on the unglazed surface.

"*B*" Includes "Blind" Insulators. Apply potential between the stud and foil around the opposite end of insulator, the foil being located to give approximately service conditions.

"*C*" Apply potential between foil located inside and outside the insulator on the unglazed parts.

"*D*" Apply potential between spiral springs coiled in cableways.

"*A*," "*B*," "*C*" and "*D*" tests consist of a flash-over voltage applied instantaneously and a 90· per cent. flash-over voltage applied for 30 seconds.

TUBES

Wet process porcelain tubes must be tested at 20,000 v. per each ⅛ in. thickness applied for 30 seconds between central stud and foil covering the outside completely except at ends where the foil is omitted to obtain the necessary striking distance.

SWITCHBOARD INSPECTION

Switchboard inspection includes the inspection of controlling apparatus for generators, motors, rotaries, transformers, etc. As the inspection of this apparatus practically checks a customer's needs for controlling his machines and various circuits, and as it necessitates an inspection of details, such as bolts and nuts, terminals, resistances, supports for various accessories, etc., the Inspector must make up the Shipping Memorandum in full to cover every part and detail of switchboard equipment, necessary to the customer.

Upon the Inspection Department, therefore, rests the responsibility for seeing that the customer is sent every item he wants, and every detail, such as bolts, braces, pipe, fittings, terminals, screws, cleats and extra wire, etc., necessary to the actual construction and installation of the board or panel. The Department must also supervise the entire construction and design with reference to electrical and mechanical faults, adaptability for service, simplicity, appearance and reliability.

While the electrical appliances of different customers may be the same, the switchboard and control equipment are dictated largely by the customer's wishes, and the circumstances governing an installation are very seldom the same for any two equipments.

In checking and inspecting switchboards and apparatus, the Requisition and Instruction Sheets, of which the Department has copies, are taken as the working basis. The Requisition is the ultimate authority as to the wants of the customer, and the board must conform explicitly to the Requisition and the attending Instruction Sheets, if any. The Engineering Notice, issued by the Switchboard Engineering Department, is an elaboration of the Requisition, and forms the basis upon which the Draughting Department and shop construct the board and furnish its equipment.

The Engineer in issuing the Engineering Notice works from the Requisition and Instruction Sheets, and hence this notice must be followed in getting the necessary apparatus built by the shop. While the Engineering Notice should be correct and is so considered by the shop, the duty of the Inspection Department is to prove that it is correct. Thus, the Department must check the Engineering Notice against the Requisition and must question or prevent any deviation from the Requisition not covered by the Instruction Sheet.

An Inspector, entering the Inspection Department, must first become thoroughly familiar with the system and routine necessary in the work. A considerable amount of routine is necessary, as every detail in reference to the inspection and shipment of switchboards must be carefully recorded and filed. All papers, such as Requisitions, Instruction Sheets, Engineering Notices, change sheets, shop orders, etc., are filed in the Department in folders marked with the requisition letters and number

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on the outside. Switchboard Drawings are similarly filed in cabinets, and a card index is kept covering the same. Drawing Lists are filed with the Requisition and other papers in the folders, where they are made up explicitly for that Requisition.

Inspectors are assigned, by slip, to inspect certain Requisitions by the Foreman or Assistant of the Department, and must keep watch over the various boards while under construction on the assembly floor. Before starting inspection, the Inspector must immediately obtain the papers on the requisitions from the file, signing for them on a sheet of paper, so that they can be readily located by looking at the name on the signed record which is substituted for the requisition papers. He must next look over the Engineering Notice and Drawing List to see if any part is missing. From these sources he can obtain the entire list of necessary drawings from which the board is built in the shop. These drawings can be obtained from the files, or can be ordered from the Blue Print Department. He next proceeds to "write up" the job, *viz.*: A pencil report covering the entire order, which afterwards is used as a Memorandum of Shipment.

The Engineering Notice is first checked against the Requisition and Instruction Sheets, to see if the engineer has covered all the items and equipment called for by the Requisition and Instruction Sheets, and at the same time the Drawings are checked against both the Engineering Notice and Requisition, to catch errors, without having to inspect the Switchboard itself. If discrepancies are found they must be taken up at once with the Engineering Department, who will correct them if possible before construction by the shop is begun. Deviations from the Requisition, errors in the capacity of instruments and apparatus, and errors in wiring, etc., include mistakes that can be discovered by this method.

Numerous other points must be always noted, but since every switchboard differs from every other it is impracticable to give instructions to cover all cases. The Inspector must use his intelligence and learn by experience.

When all the instructions in reference to the board are clear and free from errors, the Inspector must list all parts of the board in detail so that they can be identified when being packed for shipment, and checked in the various packing cases.

It must be remembered that the list of material which the Inspector makes out from the Requisition, Engineering Notice and Drawings, must include every item to be shipped on that order. Every part of any item must be listed separately in case it is necessary to disassemble the material for shipment.

The Shipping Department has authority to ship only such material as the Inspector lists on the report, no more and no less.

After the preliminary "writing up" is finished (which is generally done before the completion of the board), the Inspector must check the board during erection, day by day, keeping pace with the shop. He should, in this way, catch any faults or defects that arise, at once, and must have them corrected

by calling the Engineer's attention to them, covering the changes required by note.

When the shop has completed the erection of the switch-board and assembly of all apparatus called for on the Requisition, a report is made to the Inspection Office that so many panels, or that the material on certain requisitions, are ready for inspection and shipment. This information is recorded and is transmitted to the Inspector who handles that Requisition.

Such notification requires that the board or apparatus should be immediately and completely inspected by the Inspector assigned, who, upon finishing his inspection, should send his report to the "Final Inspector" who supervises the report, and the construction, and makes the final check inspection to catch any faults that may not have been discovered. After the "Final Inspector" has gone over the board and approves it as correct, the detailed report must be sent in at once to the office for delivery to the Shipping Department.

In some cases it is not possible to obtain all the switchboard accessories before the panels are ready for shipment. In this case a "Shortage" list is issued by the Inspector, after having been approved by the Shop and Instrument Laboratory. This shortage must cover or indicate all material not shipped or reported on the Requisition for which it is issued. When the material is obtained by the shop, it is reported for inspection. The Inspector then lists the material and inspects it, according to the above routine (excepting final inspection), and reports it to the Shipping Department as a shipment of "Shortage."

The pencil report, as given to Shippers, is typewritten, and two (2) copies are returned to the Inspectors, one to be proof read against the pencil report which accompanies it, and returned with corrections to the Shippers, and the other copy for the Inspector's file, which is also corrected by him.

After the completion of a Requisition, the papers are put in order in the folder and returned to the file.

Name Plates are ordered by the Inspector from the shop as soon as he is assigned to the job.

When the board is ready, from the inspection standpoint, to report to the shippers, the Mechanical Inspector must be notified to mechanically inspect it, after which he stamps the name plate as his approval of the board. Electrical Inspectors are likewise required to stamp all name plates, showing that electrical inspection has been made. This is done as soon as possible after the Mechanical Inspector has finished.

Controlling apparatus and protective devices are continually being changed, and improved and new ones devised. An Inspector must keep in touch with modern practice on all apparatus. Engineering Briefs and Advices embodying all changes and improvements must be kept up to date and on file. All letters and notes issued from time to time must be kept on file.

Supply shipments are handled in a similar manner to the regular switchboard shipments, except that the material is

not reported in pencil copy, but is typewritten in the Department Office on regular shipment paper. Supply orders necessitate accurate and close inspection, for while they, as a rule, do not cover individually much material, there is more opportunity for mistakes both in Engineering and Inspection, owing to the apparatus not being completely assembled.

PROJECTORS

Inspection

All projectors are inspected before the final test, to see that the drum is balanced, that no bolts, screws, nuts, or cotter pins are missing and that the rating on the name plate is correct.

Adjustment

A great deal of the testing and adjusting on Electric Controlled projectors is done during the construction of the operating mechanisms. The pilot motor coils are connected and tested for polarity, after which they are returned to the assembler for final connection. The motor is then wired to a controller and, if connected correctly, the rotor will give twelve equal shifts per revolution. After this test, the pilot and training motors are assembled, wired and thoroughly tested to insure the wiring being correct. Great care should be taken to see that all con-
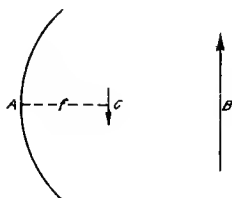
Fig. 165
MEASUREMENT OF FOCAL DISTANCE

nections are correctly made and that the mechanism is assembled properly, so that it will operate smoothly when assembled in the projector.

When the projector is assembled it is run for some time to see that it operates satisfactorily. The lamps are wired, adjusted and run at the proper current and arc voltage, care being taken that the gap at the circuit breaker in the feeding magnet circuit is of proper length, also that the screws, limiting the motion of the pawls, are set properly, after which the spring may be adjusted so that the lamp will operate at the voltage desired.

At the end of this test all lock nuts should be tightened and a general inspection of the mechanism made to see that everything is properly fastened. All projectors are given a night test to see that the mirrors are correct. When the arc is placed at the focus of the mirror, the beam should appear parallel and free from dark spots, or halos.

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Method of Measuring Focal Length

The mirror A is held up facing some object B approximately 100 feet from the mirror and a piece of ground glass or a white card C is then moved backward and forward near the focus. When the focus is reached the image of object is very distinct. The distance from the card to the center of mirror is the focal length. (See Fig. 165.)

Generator for Projectors

Until recently practically all projectors were operated on a constant potential circuit with a resistance in series with the
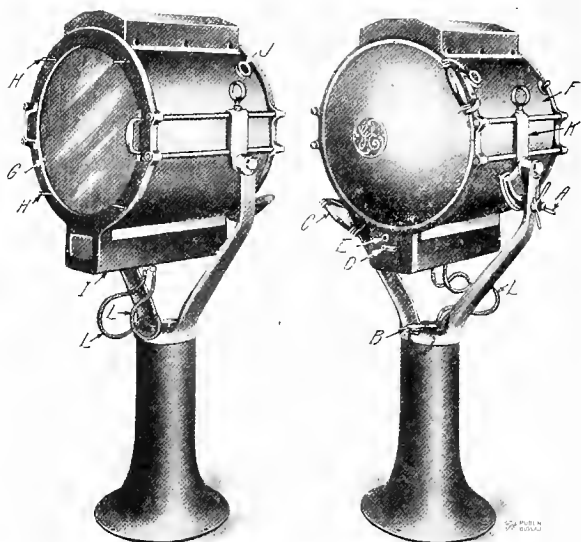
Fig. 166
HAND CONTROL PROJECTOR

arc as "ballast." A generator, Type DBR, has been designed which gives practically a constant current at a varying arc voltage. This machine eliminates the current rush at striking arc.

Projector Rheostats

A rheostat or "ballast" is connected in series with the arc when it is operated from a constant potential circuit. The object of this resistance is to prevent fluctuations of the arc current.

Projectors are fitted with four types of control, hand control, pilot house control and rope control.

The hand control projector is controlled by handles on the back of the projector case, there being a clamping wheel for locking projector on the turn-table and the right hand trunnion arm. (See Fig. 166.)
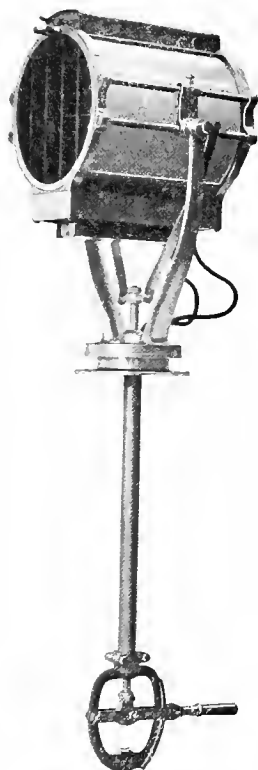
Fig. 167
PILOT HOUSE CONTROL PROJECTOR

The pilot house control projector is controlled from the pilot house by a controlling gear extending through the roof, the operation for both horizontal and vertical control being obtained by the same handle. (See Fig. 167.)

The rope control projector is controlled by cables connecting the controlling gear to the projector. As the operation for both horizontal and vertical control is done by the same handle,

the control gear may be placed in the pilot house on the bridge or on any other convenient place on board. (See Fig. 168.)

The electric control is employed for any distance from a few feet to several miles. It consists of a controller, a cable, two pilot motors, two training motors, two resistances and the necessary gears and mechanisms. The controller consists of two cylinders with operating handles, contact fingers and contact receptacles being mounted in the frame. The controller is a commutating device for changing the flux in the pilot motor armature. The pilot motor is geared to a drum provided with arms to actuate the reversing and resistance contact fingers for the training motor when the pilot motor rotates. This drum is also geared to the training motor through differential gearing to drive the drum back to the starting position. This gives a flexible control and the projector can be changed from one-third of a degree to a full revolution of the turntable, as desired.

Fig. 168
ROPE CONTROL PROJECTOR

Projector Carbons

At present, one per cent. of all projector carbons are tested. The carbons are placed in the proper lamp and burned until consumed. The kind of arc obtained should be noted; quiet or noisy, steady or wandering; and whether there is much refuse left in the lamp at the end of the run, also whether the carbons burn in focus from start to finish.

Signal Apparatus
Keyboards

Keyboards must be wired and every combination tried, care being taken to see that the proper lamps light and that the contact switch makes contact so that the lamps light simultaneously.

An insulation test is made at 500 volts. The cables are connected up to the keyboard and every combination gone through to see that the connections are correct. The connections to the receptacles should be inspected to see that there are no loose ends of wire to short circuit or ground the receptacle.

Truck Light Controllers

Truck light controllers are wired and tested to see that the proper lamps light and that the pulsator works correctly.

Diving Lamps

Diving lamps are tested under water, as specified in the Government Specifications for the apparatus, to see that leakage does not occur.

OIL SWITCHES

Potential Tests

All FK, FP and FH switches are given a high potential test between the current carrying parts and frame as stated in Engineering Brief.

Motor operated FH-2 and FH-3 mechanisms are wired up to shop circuit and operated a number of times. The tester should see that the trip coil, motor and magnetic clutch operate satisfactorily, also that the adjustment of the dog which acts as a stop for the main shaft and counter balance springs is correct as given in Engineering Brief.

Solenoid Operated Mechanism

Nearly all solenoids are tested without mechanisms. They are tested for pick up and tripping as given in Engineering Brief. Care should be taken to see that they operate between the limits given. Check also the adjustment of the control and indicating contacts.

Solenoids assembled with mechanism are tested at the voltages given in Engineering Brief. Care should be taken to see that the adjustment of the toggles, latches and balancing springs is correct. A high potential test is applied between all control circuits and frame as given in the Engineering Brief. The name plate should be checked with the tag on the switch to see that the rating and serial number correspond.

Instructions for Testing

Type F, Form T oil switch insulators are given a high potential test, as required by Engineering Brief.

Before the insulators are assembled on the metal parts, the piston tube should be given 80 lbs. air test, to see that there are no leaks in the tube castings or joints. The electrical operating valves should be operated under 80 lbs. pressure, to see that they operate freely. They should also be tested electrically while under air pressure. The tripping current of the valves is given in the Engineering Notices. After the switch is assembled and lined up, it is operated a number of times, with from 40 to 80 lbs. pressure, to see that it works smoothly.

Air operated disconnecting switches are tested, to see that they operate freely, and that they are free from leaks at an air pressure from 40 to 80 lbs. Insulators are given a high potential or arc over test.

INDUSTRIAL CONTROL

GENERAL

This includes resistances, field and starting rheostats.

Each piece of apparatus must bear the Mechanical Inspector's stamp when delivered for test. Unless it bears this stamp it must not be tested.

Before beginning the electrical test the apparatus must be given a thorough mechanical inspection by the tester.

See that all movable parts work freely, that all contacts are in good condition and that there are no loose bolts, nuts, etc.

Where beaded insulation is used, see that the leads are sufficiently filled with beads so that they cannot be short circuited by coming in contact with one another. All terminals must be a safe insulating distance apart and from the frame. All connections must be soldered. The stamping on the name plate and terminal blocks must check with Dr. List, Eng. Brief and D.S. sketch. Unless they so check, they must be sent back to shop for the necessary changes.

All resistances and field rheostats are first given a high potential test according to that specified in the Engineering Brief. The resistance of each step is then measured, and must conform to the conditions given in the Engineering Brief.

The resistance measurement will show arms reversed, interchanged, short or open circuited steps.

Remote control rheostats are operated by a ratchet wheel and pawl movement actuated by solenoids.

Besides the tests specified above, the rheostats should be operated to see that they are positive in their action and work freely. Additional tests will be specified in the Engineering Brief.

HAND OPERATED STARTING RHEOSTATS

Starting Rheostats are divided into two classes, hand operated and self-starters. In addition to the general mechanical inspection, the hand operated starters must be inspected to see that the arm always returns to the off position except when held in the running position by the retaining magnet. The contact brush must make good contact.

It is then given a high potential test and its steps measured as explained. The resistance of the retaining magnet must also be measured.

The retaining magnet must be tested to see that it will hold the starting arm in the running position with minimum current passing through it, as specified in the winding specification or Engineering Brief.

It must also be tested for release, at the voltage specified in the winding specification.

After these tests, it must be connected to a motor and given an operating test at the voltage specified in the Engineering

Brief. All overload devices should be carefully adjusted and tested as specified. Where contactors are used with controllers, they must receive the same inspection as specified under "Testing of Contactors."

Automatic Starters must be inspected for defective mechanical parts, such as cotter pins and nuts. All contactors on these devices must be operated by hand to see that their travel is not obstructed by foreign material, and all auxiliary switches or interlocks must be operated by hand, to see that they work smoothly and freely, and that they have the proper movement in relation to the movement of the contactors to which they are attached. All interlocks which are closed, when the contactor is open, must open when the contactor is closed, and all interlocks which are open, when the contactor is open, must close when the contactor is closed.

All sliding levers which are attached to the dashpots must be moved by hand, to see that they move smoothly and easily, and that there are no burred or pitted places on the buttons on the segments, across which the levers moves. See also that the lever is properly resisted by its dashpot.

ALTERNATING CURRENT APPARATUS

Special conditions, such as operation at reduced voltage or at over voltage, will be called for, either in the Drawing List or Engineering Notice. Wire the panel to an alternator running at proper voltage and frequency. In the case of an automatic compensator take taps on the compensator. (This is not a test on the compensator but is a test on the wiring of the panel. Therefore taps must be taken across the motor terminals of the panel. Proper connections for obtaining reduced voltages at these terminals can be made by closing the proper contactors.) Then test the operation of the various dashpots and contactors and see that the cycle of operation checks with what should take place, as shown on the wiring diagram. Next adjust the dashpot, so that its period of retardation is that which is called for by the Drawing List or Engineering Notice. The dashpot must be finally adjusted with an adjusting screw of such a length that the customer cannot increase the period of retardation more than the limit given in the instructions.

Next connect to a motor rated with approximately the same rating called for on the name plate of the panel. Start the motor once every four minutes for an hour. Then check the operation of the dashpot to see that it has not been changed by the test. Also feel the various coils to see that their temperature has not risen too much.

DIRECT CURRENT APPARATUS

Wire the device according to the wiring diagram given on the Drawing List, to a source of proper voltage. Adjust the dashpot to give the required period of retardation and leave the adjusting screw of such a length that the customer cannot adjust the dashpot to give a greater retardation period. Then connect

to a motor rated approximately the same as that given by the name plate stamping.

All devices which make use of current limit relays, or counter e.m.f. relays, must be tested with a motor of the same rating as that stamped on the name plate, unless permission to the contrary is given by the Designing Engineer.

On these panels measure the resistance of all circuits to see that the circuit is complete, and also to see that the resistances have the proper value. These tests are very similar to the ones made on the hand starters.

High Potential Test

All parts of the device, whether A.C. or D.C., must be given a high potential test, as specified in the Engineering Brief or Engineering Notice.

Electrical Operation of Contactors

Care should be taken when testing the contactors, to see that they close completely.

Voltage Limits

All automatic devices, except counter e.m.f., should be able to work properly at normal rated voltage and at 80 per cent. of the normal rated voltage, unless other limits are specified.

Rheostats

Every rheostat is first given a high potential test according to the Engineering Brief. The resistance of each step is then measured and must conform to the conditions given in the Engineering Brief. The resistance measurements, mechanical and electrical tests, must be followed as given in the beginning of this section.

Automatic Rheostats

All Automatic Rheostats are connected to a motor, after the resistance is measured, and given a severe operating test at the voltage specified in the Engineering Brief.

Printing Press Controllers

The resistance is first measured in the usual way and a high potential test applied at a voltage specified in the Engineering Brief. The contactor should work freely and should make good contact on the laminated brush, when operating at minimum voltage. The contactor should not close with the series resistance in, when operating at maximum voltage.

Shipment

When the apparatus is ready for shipment, the Testing Department should see that all the apparatus covered by standard Instruction Books or sketches has one securely fastened to the operating handle, before it is delivered to the Shipping Department.

VOLTAGE REGULATORS

Before setting the regulator on the test table the following defects should be looked for: Improper stamping of name plate, wrong stamping of resistance box, loose coils, loose magnet frames, loose or inclined dashpot, bent switches and studs, wrong A.C. cores; check air gap on relay, friction of relay armature, relay contacts for alignment, relay numbering, loose screws, loose terminals; see that different kinds of nuts and washers on the same stud are not used, that compensating switches on A.C. regulators are not stamped for wrong direction. Care should be taken to see that the regulator hangs true after it is installed, as any variation may cause trouble in operation. Each regulator should be wired according to its own print, and no tests should be made if the terminals are stamped wrongly or connectors are on the wrong studs. The internal connections of the regulator should be inspected for loose joints, improper connections, or poorly soldered terminals. After the regulator has been wired properly, the cores should be made to hang in the center of the magnet spools, and levers should not have too loose nor too tight a fit.

Internal Adjustments of Type TA 125 Regulators

Adjustment of springs and D.C. core of A-2, L, C-4-5-6 and TD Form L.

The D.C. core should be pressed down on the block at the top of the magnet and the lower core raised until both cores touch, then the lower core is turned $\frac{1}{2}$ turn and locked with a set screw. This core must not be touched until spring 4 has been adjusted to within 2 volts of the tripping point either way. (See Fig. 169.)

Springs

Before adjusting lever 5, Fig. 169, core 11 should be raised to its highest position and blocked, thus bringing the main contact 30 to its lowest position, to prevent contact being made between 19 and 30 while adjusting lever 5. This is necessary since, if contacts 19 and 30 came together, the proper adjustment of lever 5 could not be made. Springs 1, 2 and 3 should be loosened to their full extent, or taken out while spring 4 is being adjusted. A gauge for adjusting lever 5 is always furnished with the regulator.

To adjust spring 4, first see that the voltage on the exciter to which the direct current control magnet 6 is connected, is maintained at 65 volts. Then by taking the gauge between the thumb and index finger at A (see diagram Fig. 169), place it firmly against the bracket B and C and against the underside of the pivot sockets 7 and 8, as illustrated. Then adjust spring 4 by means of the small nut at the top of its adjusting screw, until the under side of lever 5 comes even with the top of the gauge

at 9. After this adjustment has been made, the exciter voltage should be increased to 122 volts, and at exactly this point spring 4 should be overpowered by the magnet, and the cores 12 and 13 will come together. Should it require more or less voltage to overpower the spring and bring the cores together, core 13 should be either raised or lowered, and spring 4 readjusted until the underside of lever 5 comes to the gauge as before.

The adjustment of spring 4, lever 5, and core 13 must be repeated several times to insure their being correct, as proper operation is of great importance. After the proper adjustment has been obtained, the lock nut beneath the lever on spring 4
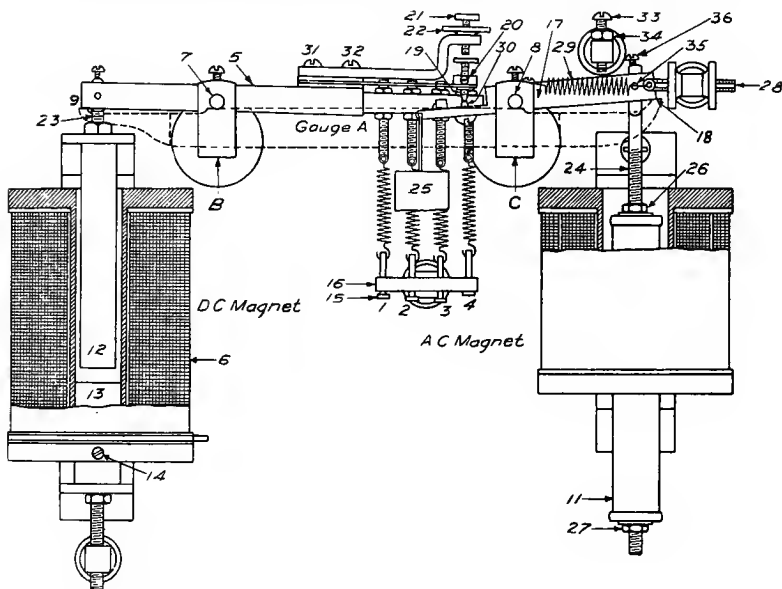
Fig. 169
MAIN CONTROL MAGNETS SHOWING PROPER POSITION OF LEVERS
WITH GAUGE IN POSITION

should be securely tightened, and the exciter voltage should then be varied over its range again, and the adjustments checked. Then screw 14, which holds stop core 13 in position, must be securely tightened. This screw should be kept tight while the adjustments are being made.

After these adjustments have been made, spring 1 should be adjusted by raising the exciter voltage to 90 volts, and at this point the spring should be under tension, bringing the small head 15 on the spring stem in contact with the spring support

16. After this has been carefully done, the lock nut below the lever on spring 1 should be securely tightened and the adjustment of spring 1 checked to see if it is correct.

Then spring 2 should be adjusted by increasing the exciter voltage to 115 volts, when it will come into action. After adjusting this spring, the lock nut beneath the lever on spring 2 should also be securely tightened and the adjustment checked.

Spring 3 should then be adjusted by raising the exciter voltage to 138 volts, this spring will then come into action in the same manner as did springs 1 and 2. The lock nut underneath the lever on spring 3 should then be securely tightened and the adjustment of spring 3 checked. When all adjustments have been made, the magnet should overpower all four springs at 170 volts.

The main contacts should then be set. Place the gauge in position as before, holding 65 volts on the D.C. coil, remove the block from the A.C. core and with both levers resting on the gauge adjust the contacts one directly over the other, lower the upper contact screw until they just make contact. Then lock with the set screw.

Adjustment of Springs and D.C. Core of F and K Regulators

The F and K regulators have their own gauge blocks on each regulator; thus the adjustments differ somewhat. The A.C. core is raised as high as possible and blocked.

The D.C. cores are not brought together as in A-2. Swing the D.C. gauge around until it nearly touches the lever, then fasten. Springs 1, 2 and 3 should be taken out while adjusting No. 4. Hold 60 volts on the D.C. magnet and bring the D.C. lever so that the bottom is just level with the white mark on the gauge, then trip. It should trip at 112 volts; if the trip is not correct use the lower core, always keeping the bottom of lever even with the gauge mark by means of spring 4. Repeat operations until the trip is right, then lock the spring and core and try again. After the trip is correct proceed with the A-2 spring test, using 80, 110 and 123 volts for springs 1, 2 and 3 respectively, with a final trip of 170 volts.

Adjusting Main Contact

Remove block from A.C. core, swing both gauges under the levers and tighten, then center the contacts one directly over the other, lower the upper contact until it just makes contact, and lock with set screw.

A.C. Magnet Core

The adjustment of the A.C. core is the same in all A.C. regulators. If the alternating voltage varies through the specified range of exciter voltage, it indicates an improper adjustment of the A.C. core. To correct proceed in the following manner: The exciter voltage should be varied from 70 to 125 volts by means of the alternating field rheostat. If the A.C. voltage rises or falls the A.C. core should be raised or lowered on the stem

until a point is reached where neither rise nor fall is recorded. If the A.C. voltage falls on increasing the exciter voltage from 70 to 125, the A.C. core should be lowered, and *vice versa.* Lock nuts on the core should be firmly set.

Adjustment of Relays

The relay coils on A-2, C-4-5-6 and TD Form L regulators are differentially wound, having two windings on each spool. The holes in the three studs to which relays are connected number outward from the base as follows: 1, 2, 3, 4, 5, 6, 7 and 8. The leads of the coils are brought directly opposite these holes and should be connected: 3 and 5 to stud A, 2. 4, 6 and 8 to B, and 1 and 7 to C. These studs are lettered from the top downward A, B and C. A wrong connection may exist with the relays operating, though not properly. If so, the coils should be tested for an open circuit or a reversed lead.

Relays F and K Type

The relay coils on these regulators are differentially wound. The leads are numbered 1, 2, 3, 4, 5, 6, 7 and 8 and are connected to the lettered studs A, B and C-1 and 6 to A; 2, 3, 5 and 8 to B, and 4 and 7 to C.

Adjustment of Relay Contacts on All TA Regulators

The manner of adjustment is the same in all cases. Press armature down on cap, set the contacts, one directly over the other and 1/32 of an inch apart. Then connect the exciter field boxes all in and close the relay switches. The voltage can then be adjusted by means of the spring fastened to the armature. This spring should be so adjusted that armature will float or hold the specified voltage on the exciter armature, for example, 45 volts on 125 volts exciter, etc.

Condensers

The condensers furnished with a regulator should be connected in multiple if more than one is required.

Starting the Regulator
Adjustment of the A.C. Generator Field Rheostat

The following adjustments are made on a TA 125 volt regulator with an exciter. Other values should be used for different no load voltages. The resistance in the A.C. rheostat should be entirely cut out unless, with no load on the alternating current generator, less than 70 volts is required on the exciter to excite the generator to give normal no load voltage. If it requires less than 70 volts, sufficient resistance should be left in the generator field rheostat to increase the exciter voltage to that amount. This is important. For generators using 125 volt exciters an excitation of 70 volts at no load is usually required to give normal no load voltage.

In cases where several alternating current generators operate in parallel, the adjustment of the field rheostat should be ob-

tained on each. If any rheostat must be turned in order to get 70 volts on the exciter, they should all be marked so that they can be turned to the proper point after the machines have been paralleled. The setting of these rheostats should never be changed except to move them slightly for eliminating cross currents between generators. Manipulating the alternating current field rheostats will not vary the division of load between the generators, which can only be obtained by varying the speed of the prime movers.

It should be remembered that with the regulator operating, turning the alternating field rheostat of any one of the generators will very materially increase the exciter voltage. Therefore, this should be avoided if possible.

Adjustment of Exciter Field Rheostat

Assuming that a 125 volt exciter is used, the best way to adjust the exciter field rheostats is as follows:

With compound wound or commutating pole exciters, full load should be applied and the exciter field rheostat turned to a point where the time required to reduce the exciter voltage from 125 to 25 volts is from 6 to 8 seconds. For shunt wound exciters, the same adjustments should be made, only under no load conditions. This can be done by loading the exciter with one or more of the generator fields, or if preferred, a water box may be used. After the proper point is found by repeated tests, the rheostat should be marked so that it can always be kept in this position when the regulator is in service.

For the standard exciter voltages given below, the exciter field rheostat should be adjusted to reduce the voltage from normal to 80 per cent. below normal, in 6 to 8 seconds with the loads given above.

NORMAL VOLTAGE	80 PER CENT. BELOW NORMAL VOLTAGE
60	12
90	18
125	25
250	50
550	110

In cases where compound wound or commutating pole exciters are used, the exciters must not be adjusted to over compound. It may be found in adjusting the exciter field rheostat that some compound wound exciters, especially those running at slow speed, will not drop their voltages to the above values with a resistance of more than three times the resistance of the shunt field circuit placed in series with them. It may be difficult in such cases to reduce the exciter voltage to the limits given, in the time specified. In such cases, it is advisable to adjust the exciters to under-compound from 5 to 8 per cent. This means changing the resistance of the compound shunt until the exciter

voltage falls off from no load to full load from 125 to 118 volts with 125 volt exciters and other exciter voltages in proportion. This very materially reduces the percentage of the compound winding. All exciters operating in parallel with it should be adjusted in the same way. A much smaller amount of resistance will then be required in the shunt field to get the adjustments specified, in the exciter field rheostats.

In cases where more than one relay is used on the same exciter, the exciter field rheostat is equally divided between the number of relays. This should be done very carefully as an unequal division will give a higher voltage on one relay than on the other, and cause sparking.

Equalizing Rheostat

In most cases an equalizing rheostat is necessary in order that the exciter load may be equally divided. The equalizing rheostat, if needed, should be placed in series with the exciter field rheostat. It must be used on the exciter that takes the greater part of the load. Enough resistance should be turned in to equalize the loads on the two exciters. The amount of resistance necessary is usually very small, and, after the rheostat is properly adjusted, it should require no further attention. If there are three exciters used, a second equalizing rheostat will probably be necessary. The regular exciter field rheostats are of no use in equalizing the loads between the exciters as they are constantly being short circuited by the regulator; therefore, the predetermined amount of resistance should be cut in and the equalizing rheostat used for load divisions.

Putting the Regulator in Service

With the connections and adjustments all properly made, the regulator can be cut in and out of service without varying the voltage. To put the regulator in service, first adjust the exciter field rheostat until the main floating contacts of the regulator just open. Then the rheostat shunt circuit switches A, B, C or D may be thrown in and the exciter rheostat immediately turned to the predetermined marked point. If, on cutting the regulator into service, it is found that the alternating voltage is not exactly at the desired value, it may be adjusted by means of the counterweight 25 or adjusting screw 28, or both.

Putting in the Second Exciter

If, with one exciter running on the regulator, a second or third exciter is required, the new exciter voltage must be made to correspond to the voltage on the bus bars, by means of the exciter field rheostat. When this voltage is correct, close the main exciter switch to bus bars, then immediately close the shunt circuit switches on the regulator, corresponding to the new exciter. The exciter rheostat should then be turned to the position marked, which reduces the exciter voltage 80 per

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cent. below normal. If the exciters equalize their load properly no equalizing rheostat will be necessary.

The regulator may be cut out of service without disturbing the voltage as follows:

Turn the exciter field rheostat out, until the relay contacts cease vibrating and remain open. Then, rheostat shunt circuit switches A, B, C or D may be opened, and the hand adjustment of the voltage is obtained as before.

Shutting Down Exciters

If it is desired to shut down an exciter when two or more are operating in parallel, first reduce the load on the machine to be cut out as low as possible by means of the equalizing rheostat, then open the main switch to the bus bars, after which open the rheostat shunt circuit switches on the exciter to be removed from service.

Line Drop Compensation

All A.C. regulators have a compensating winding on the A.C. coil to overcome line drop and to maintain a constant voltage on the lines at all loads. This may be obtained by three methods as follows:

First, by a single-phase current transformer placed in the heaviest lighting load circuit.

Second, by a special line drop compensator designed for use on the regulator on long distance transmission lines.

Third, by pressure wires brought back from the center of distribution and connected to the regulator. This, however, is not considered good practice.

In every case the following should be noted: The current transformer must be placed in one of the mains to which the potential transformer is connected, or there will be practically no compensating effect obtained owing to the current in the potential winding being displaced 90° from that in the current winding at unity power factor. This is true in either two- or three-phase circuits.

When testing the regulator care should be taken to see that none of the steps are reversed, and that each step gives the required rise in voltage. If the voltage falls, when putting on the load with the dial switch A thrown on step 2, the compensating winding is not opposing the potential. The leads from the current transformer should then be reversed. With dial switches on steps 1 and 4 there should be no voltage drop from no load to full; if there is, the A.C. lever should be inspected for binding, too much tension in dashpot, improper adjustment of A.C. core or short circuited turns in the series winding. Current transformers giving about $3\frac{1}{2}$ amperes secondary should be used, to compensate for about 15 per cent. line drop.

A potential transformer of not less than 200 watts capacity, and having a secondary voltage of about 110 volts, should be used in the circuit having the least fluctuating load.

Type TD Form G
Adjustment of Field Rheostat

The voltage should be built up to normal by means of the generator field rheostat. Then the field rheostat should gradually be turned in to a point that will reduce the generator voltage about 35 per cent. below normal. To be sure that the voltage always falls to this value, it is well to leave the field rheostat at the point given above, and then close the 5-point switch which closes the rheostat shunt circuit. If the reversing switches are then thrown to the extreme position, either up or down, the relay contacts will short circuit the rheostat and build up the voltage. : As soon as this reaches normal, the rotary switch
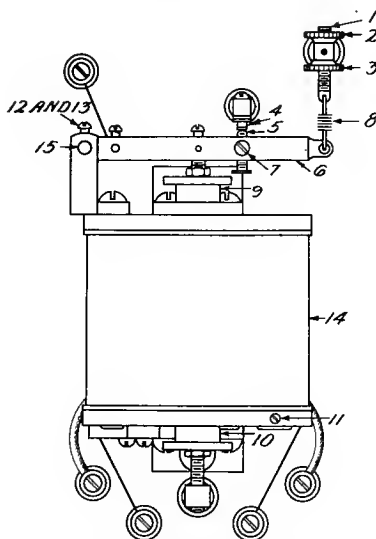
Fig. 170
MAIN CONTROL MAGNET OF TD REGULATOR

should be immediately opened to see if the generator voltage falls to the point corresponding to 35 per cent. below normal. If it does, the field rheostat should be marked, so that it can always be kept at this point when the regulator is in service. Then, by closing the 5-point rotary switch again and leaving it closed, the voltage should rise to 105 volts, and the regulator will maintain this value constantly.

Should the voltage not be within one or two volts of 105 volts, it can be adjusted to this value by the adjusting screw,

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No. 1, Fig. 170. With a lead connected from No. 4 on the regulator to any of the other binding posts on the resistance box, the voltage should always come within one or two volts of the values given in the table. A generator regulated with this arrangement may either be shunt or compound wound.

If it is desired to compensate for line drop, the voltage adjustments given above should be taken without any current flowing through the compensating winding. This will give the no load voltage. Then the load should be put on and with current flowing through the compensating winding, the voltage should increase in proportion to the load, to maintain the desired voltage. If the voltage, however, decreases with the load, leads 1 and 2 on the regulator should be interchanged. Then, it will be found that the slide on the German silver resistance, the compensating shunt can be so adjusted as to compensate for any line drop from 1 to 15 per cent.

Putting the Regulator In and Out of Service

To put the regulator in service without disturbing the voltage, the rotary switch should be closed, and then the generator field rheostat turned to the pre-determined marked point. To cut the regulator out of service, the field rheostat should be turned out until the voltage is raised slightly. The relay of the regulator will then stop working and the relay contacts will open. The rotary switch may then be opened without disturbing the voltage.

Locating Trouble

Should the voltage refuse to build up on closing the rotary switch which closes the rheostat shunt circuit, first see that the reversing switches are thrown to an extreme position, either up or down.

Look for improper connections of the regulator, such as connecting lead 6 to bus bar, and also of the rheostat shunt circuit leads to rotary switch. The latter should be connected so as to short circuit the generator field rheostat only, on closing the relay contacts.

Look for broken connections on the back of the regulator.

Look for loose connections in the binding posts. See that the screws fastening the leads in the binding posts are securely tightened.

Should the voltage immediately drop on the generator on closing the rotary switch, the connections to binding post 6 and to rotary switch have been so arranged as to short circuit the generator field instead of the field rheostats.

If a short circuit destroys the relay contacts on closing the rotary switch, the lead 6 on the regulator and also the lead connected to the rotary switch have been connected across the line, giving full voltage across these contacts.

If the regulator operates properly, but with excessive arcing at the relay contacts, first see that the condensers are all connected in multiple, and properly connected to binding posts 7

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and 13. Second, see that a sufficient number of condensers is used. See if there is not too much resistance turned in; that is, more than enough to lower the voltage 35 per cent below normal.

Should the voltage be too high, see that the lead connected to binding post No. 4 on the regulator is connected to binding post on the resistance box, corresponding with the voltage it is desired to run, as given in the tables. For example, for 230 volts, on a Type TD 250 Form G regulator, the lead connected to the binding post No. 4 on the regulator should be connected to the binding post 18 on the resistance box.

If the operation of the regulator is unsatisfactory after the above matters have been tested, and it is certain that all connections, etc., have been properly made, the adjustments of the main control magnet and relay should be checked to see if they are correct.

Heat Run

Sometimes heat runs are made on regulators to determine heating on the different coils. The run on A.C. regulators is at 115 volts and on D.C. regulators at normal voltage, the length of the run being three hours.

High Potential

High potential should be applied on all parts, to ground and between coils. The potential between coils must not be instantaneously applied, nor must the circuit be suddenly broken. The high potential terminals should be placed on the coil under test, and the voltage gradually raised on the alternator to normal and then reduced in the same manner until zero voltage is reached, before removing the high potential cables.

Resistance Measurements

Measurements should be carefully taken on relay coils, D.C. magnet coils, A.C. magnet coils and resistance box.

The variation in resistance must not exceed that specified in the Engineering Brief.

MERCURY ARC RECTIFIERS

The essential features of this apparatus consist of an exhausted glass vessel, containing mercury, having two working anodes PP a cathode Q and a starting anode S. (See Fig. 171.)

Operation

The wiring of the panel, and the adjustment of the circuit breaker should be checked, taking care to see that the setting
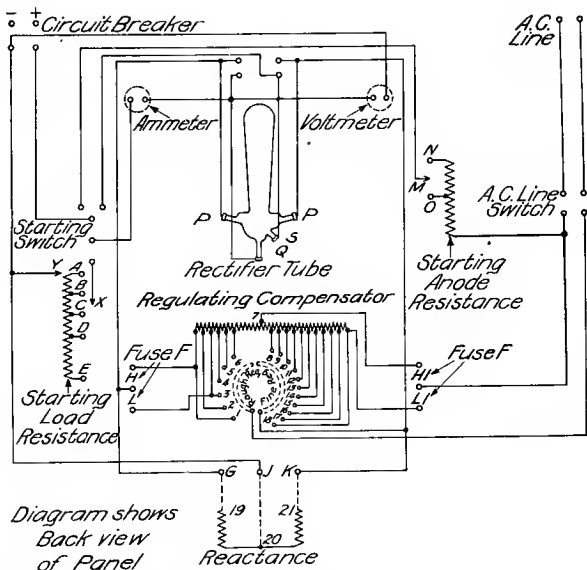
Fig. 171
CONNECTIONS OF LATEST DESIGN, SINGLE-PHASE MERCURY ARC RECTIFIER

of the circuit breaker does not exceed the rated capacity of the tube. Connect the starting load and starting anode resistance, place fuses F and the rough regulating dial switch in the position (the studs are all numbered) corresponding to the required A.C. voltage. After making these connections close the A.C. switch and the circuit breaker. Hold the starting switch in the lower position and rock the tube gently by the handwheel connected to the holder. This will make and break a mercury

bridge between the starting anode S and the cathode Q which will cause a slight flash, starting the rectifier. Under ordinary conditions a single flash should be sufficient to start the tube, but in cold weather, or when a tube is run at lower than rated voltage, more than one shake may be necessary.

In cold weather hold the spring switch, in the lower or starting position, for at least 30 seconds, so that the tube will be somewhat warmed before full load is thrown on. When the hand is removed from the spring switch, it will automatically move into the upper position and transfer the rectified current from the starting resistance to the load, it will also open the starting anode circuit.

If the load is a battery, with a higher voltage than that of the rectifier, the tube will go out when the spring switch moves to the load position. In this case, raise the voltage of the rectifier by moving down (counterclockwise) the fine regulation switch; the tube will then start again. In case the desired current is not obtained, the voltage should be further increased by moving up (counterclockwise) the rough regulation switch, a sufficient number of steps, until the desired current and voltage are obtained. After once determining the position of the rough regulation switch, regulation can be obtained from the fine regulation switch.

Always note the following points: The positive terminal of the storage battery must be connected to the positive terminal of the panel. The tube must be handled carefully. The setting of the circuit breaker should not exceed the rated ampere capacity of the tube. A tube should never be used above its rated ampere capacity, unless instructions are specifically given to do so.

GENERAL ELECTRIC TEST TRACKS

As the work on the General Electric Test Tracks is almost entirely experimental a large number of the tests require special instructions. The following rules, however, have been issued relative to the operation of trains on these tracks, as well as instructions for obtaining data, in testing apparatus.

No test should be started nor should changes be made in any test without instructions from the office of the Supervisor of Test Tracks.

All data should be recorded upon special record sheets and supplementary column sheets, or upon the special form sheets provided for that test.

All data sheets should contain the name of the man in charge of the test, and date of test, while all supplementary column sheets should also contain in the upper right hand corner the number of the record sheet to which they belong.

Electric Locomotives

Special form sheets are printed for testing locomotives, which should be carefully filled out. The procedure of testing is as follows:

1st. Inspect the locomotive carefully for any loose material or refuse that may be in the cab and frame, including the rheostat, controller compartments, and especially around the motors, if the open gearless type is used.

2nd. Test the control circuit to see if everything operates correctly and the contactors pick up in the proper order. The latter can be determined from the D.S. print of connections. (See Figs. 172 to 175.) Inspect the wiring to see that all terminals are properly soldered, tight, and secured with lock washers; also that all parts of both the main auxiliary circuits are properly insulated and that all wiring is so secured as to prevent the insulation being cut from chafing.

3rd. Take the drop on grids. This may be done with a storage battery and low reading voltmeter, or a shunt and special meter may be connected in series with the line and the drop read across the grids, by first setting the brakes on the locomotive and then throwing the controller on the first notch. In the latter method, the current should not be held on the grid longer than is necessary to secure a reading, otherwise the grids will heat excessively. A variation in resistance of 20 per cent. is allowed from that given in the D.S. sketch.

4th. Test the air brake system and see that the safety valve, air compressor governor, reducing valves, etc., operate at the pressures called for in the Engineering Notices. The brake rigging should be inspected to see that all cotter pins and lock nuts are in place.

5th. Run the locomotive for a bearing test. If, at the end of 10 or 15 miles on small slow speed locomotives, and 75 or 100
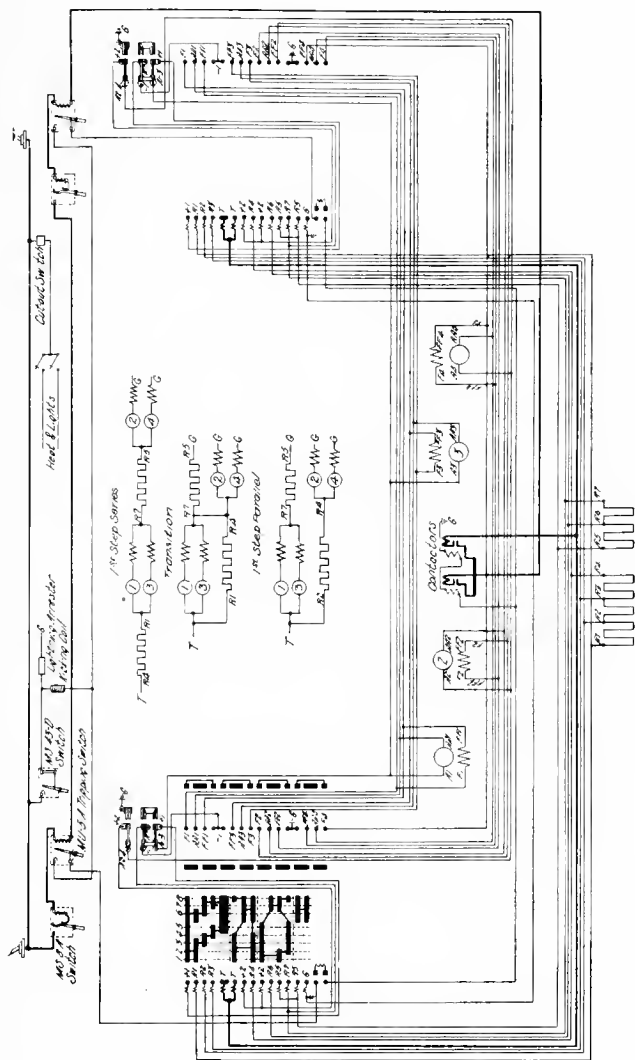
Fig. 172

DIAGRAM OF K-35-B CONTROLLER

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Fig. 173
DIAGRAM S.G.E. MULTIPLE UNIT CONTROL

miles on high speed locomotives, the bearings show no excessive heating and the temperature is not increasing as the run continues, they may be passed. If, however, they get too hot the packing should be removed and the box repacked with fresh waste. It is sometimes found necessary to remove the bearing and scrape it; this, however, should not be done except by order of the Supervisor of the General Electric Test Tracks or his assistant. As soon as the bearings are in good condition and run cool, the test should be discontinued.
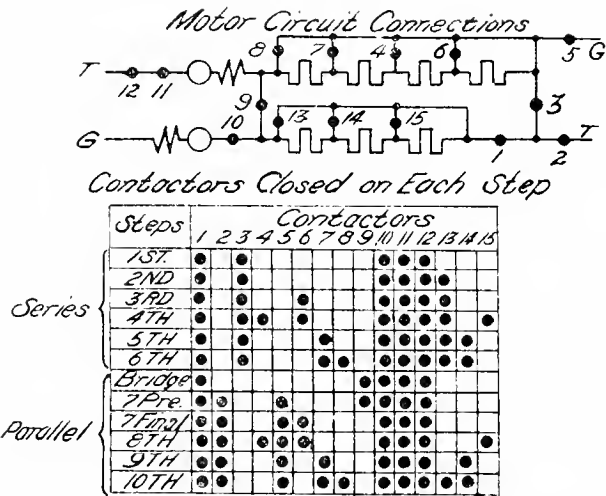
Fig. 174
GENERAL SCHEME FOR S.G.E. CONTROL

Mounting Motors on Trucks

Before mounting motors on trucks, the following measurements should be taken: Compare bore of gears with size of axle for gears; compare bore of axle liners with size of axle for liners; compare the distance between wheel hubs with the length of the motor; axle liner flanges and gear hub; compare the distance between the center of axle and suspension bar face on truck with the distance between the axle box centers and face of motor under nose suspension.

After these dimensions have been checked, and the motors have been found to fit on the truck, the key for the gear should be fitted in the key-way and the gear put on, care being taken to get right side of gear next to the hub of wheel, and to see that all lock washers and cotter pins are in place. The motor should
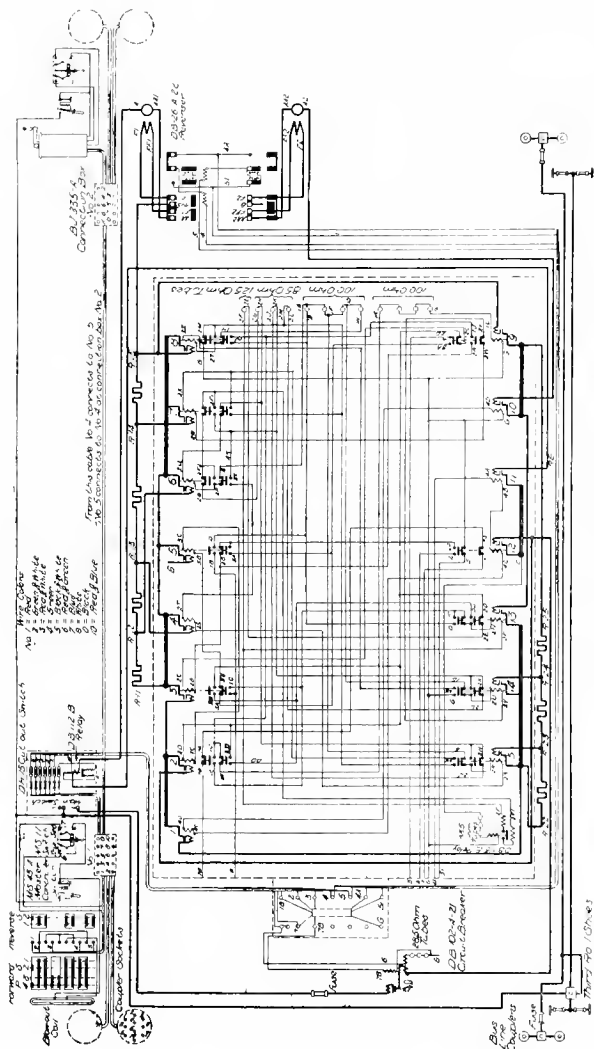
Fig. 175

AUTOMATIC RELAY CONTROL DIAGRAM

then be hoisted by the two lugs opposite the axle bearings with a two hook chain, and the motor placed on the axle without axle linings. The motor can then be lowered in place, by allowing it to revolve around the axle until the nose suspension rests on the suspension bar. The chains can then be hooked in the two lugs nearest the axle bearings and raised enough to allow the axle linings to be put in place. The axle caps, gear cover and strap fastening the motor to the suspension bar can then be put on and the installation is complete.

Before the motors are put into service or the car run as a trailer, the motor bearings and gears should be properly lubricated.

Trolley Bases

Test sheets should contain the following data:

Number and size of spring (outside diameter, free length, number of turns and size of wire). Position of tension adjusting screw during test. Length of pole from pivot to center of trolley wheel. Style of harp and wheel. Length and tension of springs with pole, in horizontal and 45 degree positions.

Pull Curve

This curve is taken by measuring the vertical pull in pounds at the center of trolley wheel for different heights of the wheel. The "height" of the wheel is the vertical distance of the center of the trolley wheel above its position when the pole is horizontal. (For pantagraph trolleys the height is the distance of the top of the pan above its position when locked.) In taking this test a rope should be fastened about the wheel and readings of pounds pull taken, both going up and coming down.

Service Heat Runs on Motors

These heat runs are made on motors under as nearly as possible the same conditions as will obtain in service. By making a number of heat runs under various conditions data is obtained from which the thermal characteristics of the motor are determined. These curves show the relation between the ratio of distribution of losses (ratio between watts loss in field and in armature) to the degrees (Centigrade) rise per watt loss for the armature and for the field.

The instructions for the test include the following points:
(a) Weight of train.
(b) Line voltage to be held.
(c) Accelerating current required.
(d) Schedule (includes length of run, time power is on, time of coasting, time of braking, and time of layover).

The following readings must be taken before starting the test: Resistance of field, total and partial resistance of armature.

In order to facilitate the measurement of armature resistance during the run, resistance readings are taken between commutator bars half way between brushes. These bars should be prick punched in order that all measurements can be made

between the same points. The ratio between the partial resistance to the total resistance is a constant from which the total resistance can be calculated.

The following must also be taken during the test:

Air temperatures, velocity and direction of wind, readings during test (taken every hour), field resistance, partial resistance of armatures of alternate motors, temperature by thermometer of field spools and frame, air temperatures.

During the run a record is kept of the schedule, direction of wind, weather conditions and all points of any interest in connection with the runs.

Records of the line voltage and amperes motor are taken with graphic recording meters for a couple of runs in each direction during the hour.

When the temperatures of the motors have become constant, the test is stopped. Besides the regular hourly readings the following temperatures are taken: Armature, core surface, and conductors; commutator; field spools; frame.

These readings should be taken indoors in order to avoid all draughts.

Wheel Slipping Tests

If this test is called for, the locomotive should be first coupled to one or more cars upon which the brakes are set so that it cannot move. The controller is then notched up step by step until the wheels slip, readings of amperes and volts line being taken on each step. After slipping the wheels the locomotive should be moved forward about a foot, the track well sanded and the test continued, starting with the controller notch at which the wheels slipped unsanded. This test must be made with the locomotive entire, an individual motor, or a truck, as may be called for in the instructions. In every case the wheels must rest upon a level piece of track.

Distribution of Potential Among the Motors

Connect as many motors in series as possible and take readings of volts across each motor and amperes at the loads specified in the Engineering Notice. Do this for all sets of motors in series, one set at a time.

After these tests are completed, the locomotive should be inspected, as called for on the locomotive record sheets. A high potential test, as specified in the Engineering Notice, finishes the test.

Train Friction

Train friction curves show the relation between the train or car friction expressed in pounds per ton and speed in miles per hour.

There are two methods by which car friction may be obtained, coasting tests and free running.

Friction from Coasting Curves

The test should be made on a straight and preferably level track. The car is accelerated to a speed slightly greater than the highest speed called for on the friction curve and allowed to coast. Speed should be measured with a speed recording instrument. Runs should be made in both directions.

From the rate of retardation at any point, the retarding force is calculated which represents the total car friction at that speed.

Friction by Free Running

With the car running at constant speed, readings of speed, volts line and amperes should be taken, preferably with graphic recording meters. The input to the motors, minus their electrical losses, gives the power absorbed in friction at a given speed.

The test sheets should contain the following data:

Weight of car or train.

Diameter of wheels and speed readings, where a graphic speed recorder is used. If the free running method is used, the number of motors, rating and gear ratio, must be given.

Operating Rules

The following rules govern employees of the General Electric Company in the operation of cars or trains on the General Electric Test Tracks: Every man must pass an examination on these rules before being allowed to act as a conductor or motorman.

GENERAL NOTICE

The following rules govern employees of the General Electric Company in the operation of cars or trains on the General Electric Test Tracks or elsewhere, when under the direction of the Supervisor of the General Electric Test Tracks.

These rules take effect June 15, 1908, superseding all previous rules or instructions inconsistent therewith. Special instructions may be issued by the proper authority.

G. E. EMMONS,

Manager Schenectady Works.

Approved:

W. B. POTTER,

Eng. Ry. and Tract. Dept.

GENERAL RULES

No car or train must be taken beyond the yard limit without a written train order. (See Fig. 176.) Shifting cars in the yard is not included under this order, although the following rules apply in all cases.

Every employee, while on duty connected with the railroad, is under the authority and must conform to the orders of the Supervisor of the General Electric Test Tracks.

There shall be an operator in charge of each car or train who shall be responsible for the safe and intelligent operation of the same.

Employees are required to take great care to prevent injury to themselves and others, and are required to inform themselves regarding the condition of equipment and the location of all posts, signals, switches, etc., along the line, which might in any

GENERAL ELECTRIC TEST TRACKS

Train Order No.................

Schenectady, N. Y.,.................19....

Car No............ ......Time Given.............................

Motorman..................... Conductor.......... ....

Signed.................... ....

The blanks below must be filled out and train order handed in as soon as run is completed.

Miles Run...........No. of Trips Run.......................

Operation...

Fig. 176
STANDARD FORM OF TRAIN ORDER

way be dangerous to life or to the safe operation of the road. Any defect should be immediately reported.

The Supervisor of the Test Tracks must be conversant with the rules, and see that they are understood by his subordinates, enforce obedience to them and report to the proper officer all violations, and action taken thereon.

Every employee of this Company whose duties are prescribed by these rules must be conversant with every rule. He

must render all the assistance in his power to carry them out, and immediately report any infringement of them to the head of the department.

If in doubt as to the meaning of any rule or special instructions, application must be made at once to the proper authorities for an explanation.

GENERAL ELECTRIC TEST TRACKS

Schenectady, N. Y.,................19....

This is to certify that I have this day examined Mr..

regarding his knowledge of the book of rules and I find him qualified to act as conductor or member of train crew on the General Electric Test Tracks.

Signed..

STANDARD FORM FOR CONDUCTOR AND TRAIN MEN CERTIFICATE

GENERAL ELECTRIC TEST TRACKS

Schenectady, N. Y.,................19....

This is to certify that I have this day examined Mr..

regarding his knowledge of the book of rules, the handling of cars, and the operation of air brakes, and find him qualified to act as motorman on the General Electric Test Tracks.

Signed..

Fig. 177
STANDARD FORM FOR MOTORMAN CERTIFICATE

Employees are required to assist in keeping the premises in a neat and orderly condition.

No employee will be allowed to absent himself from duty without special permission from the supervisor.

Before men are allowed to act as conductors or members of train crews where their duties will require them to give signals,

they must pass an examination and be furnished with a certificate to show that they understand the book of rules. Before acting as motormen they must have passed an examination and be furnished with a certificate, to show that they understand the operation of air brakes and the handling of cars. (See Fig. 177.)

Any car or train operated on the General Electric Test Tracks by anyone not directly under and reporting to the Supervisor of the General Electric Test Tracks, must have a pilot who will have full charge and be held responsible for its movement, as if he was running it himself.

All signals must be used strictly in accordance with the rules, and every one must keep a constant lookout for signals.

Men operating trains will be held responsible for the violation of any of the rules and they must take every precaution for the protection of their trains, even if cases arise not provided for by the rules.

In giving signals governing movements of cars, the end of the car at which the motorman is operating is considered the head end.

In bringing cars into the car barn yards, a full stop must be made just before starting down the grade into the yard, and slow speed must be maintained while coming down the grade and into the barn, with the car under full control all of the time.

Any work car or train operating on the track will be given working limits. When coming to the barn after finishing work it must run slow and under full control, and a careful watch must be kept for signals.

When necessary to issue instructions regarding special conditions, bulletins will be posted on the bulletin board in front of the office in the car barn. All men must keep themselves informed in reference to these bulletins, and be governed accordingly.

Ignorance of these rules will not be an excuse for neglect of duty.

In all cases of doubt or uncertainty the safe course must be taken and no risks run.

Whistle Signals (From Motorman)

One long blast is the signal to apply hand brakes to stop.

Two long blasts is the signal to throw off brakes.

Two short blasts is the answer to any signal.

Three short blasts when train is standing is the signal that train will back up.

Four long blasts is the signal to call in all flagmen.

Four short blasts is a call for signals.

Five short blasts is a signal to flagman to go back and protect rear of train.

Two long blasts followed by two short blasts is a crossing signal or for a warning at places where people are likely to cross the track.

The engine or car bell must be rung or whistle blown when the engine or car is about to start.

A train must not start until the proper signals are given.

When a signal (except a fixed signal) is given to stop a train, it must be acknowledged by two short blasts of the whistle.

The unnecessary use of either the whistle or bell is prohibited. They will be used only as prescribed by rule or law, or to prevent accident.

Bell Cord Signals (from Conductor)

Two bells when train is standing is signal to go ahead.

Two bells when train is running is signal to stop at once.

Three bells when train is running is signal to stop at next station.
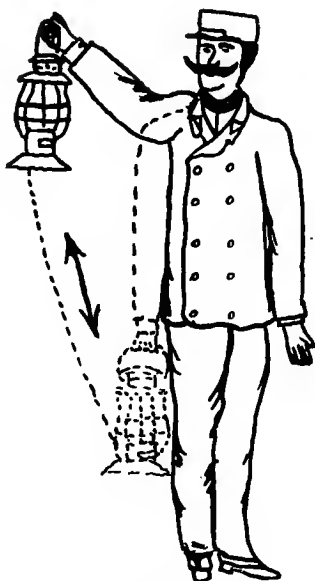
Fig. 178
GO AHEAD—A MOTION UP AND DOWN

Three bells when train is standing is signal to back up.

Four bells when train is running is signal to reduce speed.

Four bells when train is standing is signal to apply or release air brakes.

Five bells when train is running is signal to increase speed.

Flag, Hand and Lamp Signals

(See Figs. 178-183.)

Swung across the track is the signal to stop.

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Raised and lowered vertically is the signal to go ahead.

Swung vertically in a circle across the track when the train is standing is the signal to back up.

Swung vertically in a circle at arm's length across the track, when train is running, is signal that train has parted.

Swung horizontally in a circle, when train is standing, is the signal to apply air brakes.

Held at arm's length above the head is the signal to release air brakes.
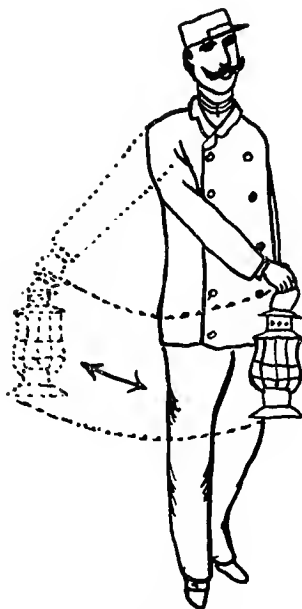
Fig. 179
STOP—A MOTION CROSSWISE WITH THE TRACK

Any object waved violently by anyone on or near the track is a signal to stop.

Flags of the prescribed color must be used by day, and lamps of the prescribed color by night.

Night signals must be displayed from sunset to sunrise. When the weather or other conditions obscure day signals, night signals must be used in addition.

A blue flag by day or a blue light by night displayed at one or both ends of an engine, car or train, indicates that workmen are under or about it. When thus protected it must not be

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coupled to or moved. Workmen will display the blue signals, and the same workmen are alone authorized to remove them. Other cars must not be placed on the same track so as to intercept the view of the blue signal, without first notifying the workmen.

Placing Lamps or Flags

Any lamp or light at night on the track between the rails signifies immediate stop.

Red signifies danger and is the signal to stop.

Fig. 180
BACK UP—A MOTION IN VERTICAL CIRCLE

Yellow signifies caution and is the signal to go slowly.

Green signifies safety and is the signal to go ahead.

When running after dark each train or car must always be provided with a head light on the forward end.

Train crews must see that their trains are supplied with a portable telephone set and a red flag, while it is being operated on the track.

When a train stops or is delayed, in cases where it may be overtaken by another train, a flagman must go back immedi-

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ately a sufficient distance with stop signals, to insure full protection.

Two "Slow" boards placed at right angles along the track reading on their faces "Reduce Speed to ——Miles per Hour" will indicate the rate of speed at which the track may be used
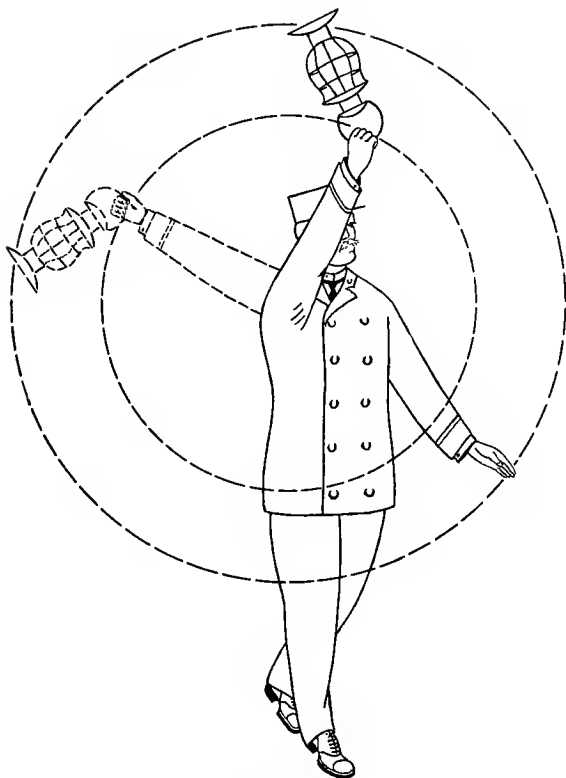
Fig. 181
TRAIN HAS PARTED
SWUNG VERTICALLY IN A CIRCLE AT ARM'S LENGTH ACROSS
THE TRACK WHEN THE TRAIN IS RUNNING

between the boards. The rate of speed indicated on the Slow boards must not be exceeded. The back of the Slow boards will be marked "Resume Speed." Yellow lights will be suspended by night from these boards.

When the Semaphore is used, the arm in a horizontal position by day, or a red light by night, indicates danger—stop. The arm at an angle of forty-five (45) degrees, or a yellow light by night, indicates caution. The arm in a vertical position by day, or a green light by night, indicates safety—proceed.
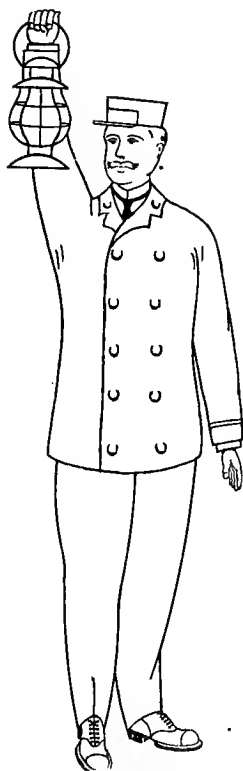
Fig. 182
RELEASE AIR BRAKES
HELD AT ARM'S LENGTH ABOVE THE HEAD WHEN TRAIN IS STANDING

Any semaphore placed along the track must be considered in use, when the arm is in place, and all movements of cars or trains must be governed accordingly, unless permission is given in the train orders to disregard it.

A white light by night on a fixed signal, or the absence of a signal where a signal is usually shown, must be regarded as a stop signal and the fact reported to the Supervisor.
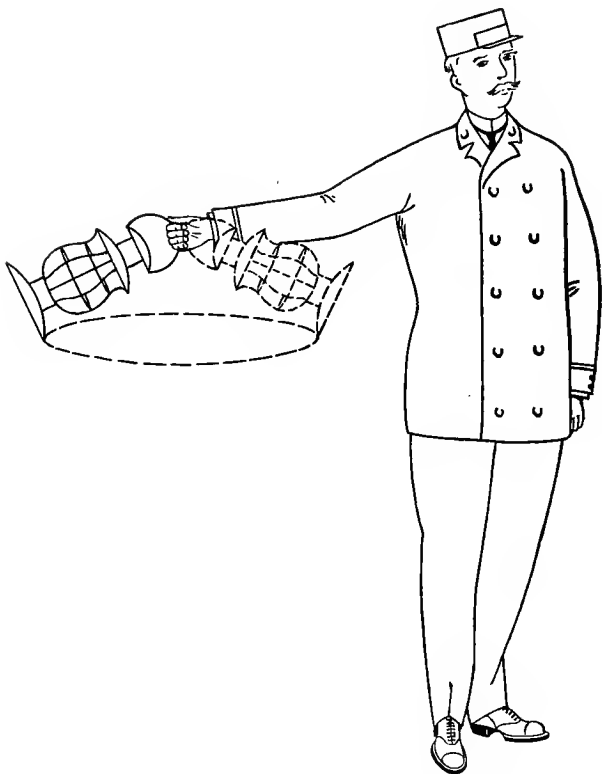
Fig. 183
APPLY AIR BRAKES
SWUNG HORIZONTALLY IN A CIRCLE WHEN THE TRAIN IS STANDING

GASOLENE ENGINE TESTS

After the set has been assembled, the generator is run as a motor to wear the engine bearings and smooth up the piston and cylinder surfaces. The engine is then piped up to the radiator or cooling tank and the exhaust connected to a suitable muffler or to a pipe leading out of the room, and the carburetor is piped to a suitable gasolene supply.

The generator is connected through suitable switches, circuit breakers and instruments to the load. The ignition apparatus should be tested for short circuits, and to see that the connections are made to the right spark plugs in sequence at the proper time.

The spark plugs should be tested, to see that there is no leakage through the insulation, by placing mica between the sparking terminals and then turning on the high tension current.

The valve timing of each engine should be taken by means of a protractor level, placed on the crank cheek, or by a disc marked off in degrees, fastened on the end of the crank shaft, readings being taken in degrees when the valves open and close. Diagrams are made from this data.

The engine, when first started, is run on no load for 4 or 5 hours, when preliminary adjustments are made in the position of the spark and the gasolene throttle. Water, lubricating oil and compression leakages are located and the action of each auxiliary part of the set is independently inspected with a view to finding any flaw affecting operation. In adjusting the gasolene throttle the exhaust gases are a good indication as to whether the proper fuel mixture is being used.

Dark colored dense smoke indicates that there is an excess of gasolene in the mixture.

White dense smoke shows an excess of lubricating oil. Thin blue, or nearly invisible smoke, indicates a normal mixture and good ignition.

The cooling water passing into the cylinders should be about 60 degrees C. and the amount of water should be regulated so that the outgoing water will be about 80 degrees C., in order to obtain the best results.

The following give some of the more important points during the test requiring record: Time of spark, position of main throttle, position of gasolene throttle, amount of cooling water, temperature of incoming cooling water, temperature of outgoing cooling water, amount of gasolene used, specific gravity of gasolene, temperature of room, condition of exhaust gases, proportion of hot and cold air in carburetor.

A careful record must be kept of the output of the machine that is used as load; readings of amperes and volts armature, amperes and volts field, and any load that the exciter may be carrying must be carefully recorded. If there is a direct driven

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air compressor, note should be made as to the pressure that it is pumping against, and the length of time that the governor keeps it pumping.

The following dimensions should be obtained and recorded: Diameter of piston, area of piston, length of stroke and area of clearance, including the whole space above the cylinder at the top of stroke.

GRAPHIC RECORDING METERS

In order that data on the graphic meter records may be complete and accurate, the following points should be observed:

1. Adjust meter pens on their zero lines when the instrument is horizontal.

2. The mark made by the time marker pens should be distinct from the ruled lines and should generally come between the first and second lines from the zero.

3. If it is not possible to obtain the exact exciting current called for, the exciting current actually used should be marked on the record as well as the correct value.

4. The time that the test commences should be marked on each record.

5. In acceleration tests, approximately $\frac{3}{4}$ in. spacing should be allowed between the 5 second ticker marks.

6. The meter should be started 10 seconds before the record begins, to allow the paper to be running at uniform speed.

7. There should always be a jog (mark) on the ticker marker record to connect the various records together. In addition to this a jog on the ticker record should be made when passing each mile post. If a mile post jog is omitted, special note should be made of the fact on the notes sheet referring to that test.

8. When starting a new roll three sets of check marks should be made, with the paper at rest, to show the relative position of the ticker, speed, and meter pens.

9. Check recording meters and indicating meters several times during the test.

10. When a roll of paper is completed it should be stamped on the back with a stamp provided for that purpose, and the blanks filled in with the data called for.

SPECIAL TESTS FOR ENGINEERING INFORMATION

The special tests which are sometimes made on machines for engineering information consist of potential curves on the commutator of D.C. machines, oscillograph curves, running torque curves, parallel operation tests, core loss separating tests, and special controller motor tests. With the exception of parallel operation and controller motor tests, all the above tests have been previously discussed.

Parallel operation tests are made on different machines to ascertain whether they will run in multiple. Each case usually differs from every other, consequently it is impossible to discuss the tests in detail. In general, for good parallel operation the characteristic of the shunt generators should be the same. Compound wound machines should have similar characteristics and furthermore the series field should be connected through an equalizer.

In order to insure good parallel operation of A.C. machines, their characteristics and wave form should be similar. It is absolutely necessary that the prime movers have good regulation and that the angular velocity of the revolving parts should not vary more than $2\frac{1}{2}$ electrical degrees during any part of a revolution.

Special controller motor tests are sometimes made as follows: The machine to be tested is belted to a D.C. machine of proper capacity, which should be run long enough under load to allow the armature resistance to become constant. With the machines at rest the controller is brought to the first position. With the voltage and frequency held constant, the current and voltage when constant in each phase are also read. Read also the speed of the motor and D.C. machine as well as the D.C. output. These readings should be taken on each step up to the running position. With the machine decelerating the same readings should be taken which should check with the acceleration readings.

MARINE GENERATING SETS

The Marine Generating Sets consist of vertical type double acting steam engines direct connected to a multi-polar generator.

ENGINE

Single cylinder engines are used with generators from 2½ to 50 kw. capacity, and vertical tandem compound engines with machines from 25 to 75 kw. capacity. The engines are standard commercial machines. In addition the Company manufactures for the Government cross-compound generating sets in capacities of 16, 24, 32, 50 and 100 kilowatts.

Steam Pressures

The ratings of the standard single cylinder engines are based on a steam pressure of 80 lbs. non-condensing, with the exception of the 50 kw. engine, the rating of which is based on 100 lbs. steam pressure. At 80 lbs. this set will carry 15 per cent. overload for 2 hours, but it can be operated at pressures up to 120 lbs., either condensing or non-condensing. If higher boiler pressures are used a suitable reducing valve must be placed in the steam line to give the desired pressure. For steam pressures of less than 80 lbs., single cylinder engines are fitted with large cylinders, to operate at pressures ranging from 35 to 60 lbs.

The tandem compound engines are designed to operate economically at 125 lbs. condensing, or 140 lbs. non-condensing.

The Navy standard cross-compound units are operated at a pressure of 150 lbs. (for the 50 and 100 kw. sizes, and 100 lbs. for the 8, 16, 24 and 32 kw. units) either condensing or noncondensing. They are guaranteed to operate satisfactorily at pressures either 20 per cent. above or below normal, except at 80 per cent. steam pressure, and under these conditions carry full load, with atmospheric exhaust when but 90 per cent. load on the generator is to be carried.

Unless otherwise advised by engineering instructions, all engines must be tested at the pressures given in the following tables. These tables are a complete list of all types of engines manufactured.

DIRECT CONNECTED GENERATING SETS WITH SINGLE-CYLINDER ENGINES, WITH GRAVITY SYSTEM OF LUBRICATION

Classification	Dia. Cylinder Ins.	Stroke Ins.	Dia. St. Pipe Ins.	Dia. Ex. Pipe Ins.	Volts Full Load	Amp. Full Load	Steam Pressure Lbs.	Vacuum in In.
MP 4- 2½-700	3½	3	¾	1	110	23	80	
MP 4- 4 -600	4½	4	1	1½	110	36	80	
MP 4- 7 -550	5	4½	1¼	1½	110	64	80	
MP 6-10 -450	6½	5	1½	2	110	91	80	
MP 6-15 -400	8	6	2	2½	110	136	80	
MP 6-20 -360	9	7	2½	3	125	160	80	
MP 6-30 -305	11	8	3	3½	125	240	80	

DIRECT CONNECTED GENERATING SETS WITH SINGLE-CYLINDER ENGINES, WITH FORCED SYSTEM OF LUBRICATION

Classification	Dia. Cylinder Ins.	Stroke Ins.	Dia. St. Pipe Ins.	Dia. Ex. Pipe Ins.	Volts Full Load	Amp. Full Load	Steam Pressure Lbs.	Vacuum in In.
MP 4- 7-550	5	$4\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	110	64	80	
MP 6-10-450	$6\frac{1}{2}$	5	$1\frac{1}{2}$	2	110	91	80	
MP 6-15-400	8	6	2	$2\frac{1}{2}$	110	136	80	
MP 6-20-360	9	7	$2\frac{1}{2}$	3	125	160	80	
MP 6-30-305	11	8	3	$3\frac{1}{2}$	125	240	80	
MP 6-50-280	12	11	$3\frac{1}{2}$	4	125	400	100	

DIRECT CONNECTED GENERATING SETS WITH TANDEM COMPOUND ENGINES, WITH FORCED LUBRICATION

MP 6-25-450	$6\frac{1}{2}$-$10\frac{1}{2}$	5	2	3	125	200	140	0
MP 6-35-400	$7\frac{1}{2}$-$12\frac{1}{2}$	6	2	$3\frac{1}{2}$	125	280	140	0
MP 6-50-400	$9\frac{1}{2}$-15	6	$2\frac{1}{2}$	4	125	400	140	0
MP 6-75-310	$10\frac{1}{2}$-18	8	3	5	125	600	140	0

DIRECT CONNECTED GENERATING SETS WITH CROSS COMPOUND ENGINES, U. S. NAVY TYPE WITH FORCED LUBRICATION

*MP 6- 8-550	5	$4\frac{1}{2}$	$1\frac{1}{4}$	2	125	64	100	25
MP 6- 16-450	$5\frac{1}{2}$- 9	6	$1\frac{1}{2}$	3	125	128	100	25
MP 8- 24-400	$6\frac{1}{2}$-$10\frac{1}{2}$	7	2	$3\frac{1}{2}$	125	192	100	25
MP 8- 32-400	$7\frac{1}{2}$-12	8	$2\frac{1}{2}$	4	125	256	100	25
MP 8- 50-400	$7\frac{1}{4}$-14	8	3	5	125	400	150	25
MP 8-100-350	10 -18	10	$3\frac{1}{2}$	6	125	800	150	25

* This set uses a single cylinder engine.

DIRECT CONNECTED GENERATING SETS WITH SPECIAL CYLINDERS FOR LOW STEAM PRESSURES

MP 4- 7-550	7	$4\frac{1}{2}$	2	$2\frac{1}{2}$	110	64	50	0
MP 4- 7-550	9	$4\frac{1}{2}$	2	$2\frac{1}{2}$	110	64	35	0
MP 6-10-450	$7\frac{1}{2}$	5	2	$2\frac{1}{2}$	110	91	60	0
MP 6-10-450	9	5	2	$2\frac{1}{2}$	110	91	50	0
MP 6-15-400	10	6	$2\frac{1}{2}$	3	110	136	50	0
MP 6-15-400	$12\frac{1}{2}$	6	$2\frac{1}{2}$	3	110	136	35	0
MP 6-20-360	11	7	3	$3\frac{1}{2}$	125	160	50	0
MP 6-20-360	13	7	3	4	125	160	35	0
MP 6-30-305	16	8	3	4	125	240	35	0
MP 6-50-280	$17\frac{1}{2}$	11	$4\frac{1}{2}$	6	125	400	50	0

The above are fitted with a gravity system of lubrication with the exception of the 50 kw. engine which uses forced lubrication.

Lubrication

Two systems of lubrication are used, gravity and forced.

In the gravity system all the main bearings of the engine are lubricated from an oil reservoir attached to the engine (refer to Fig. 185); each bearing being provided with an adjustable sight feed for regulating the flow of oil. The waste oil collects in a bedplate reservoir, from which it can be drained, filtered and used over again. The bearings of the governor and valve gear are lubricated by compression grease cups.

In the forced system the lubricant is passed under pressure to the various parts of the engine by the mechanism shown in Fig. 184. The base of the engine forms an oil tank to which is attached a small plunger pump driven by an eccentric on the shaft. The oil is forced through grooves in the main bearings, drilled holes in the shaft connecting these grooves with the crank pins. The oil is also forced to the wrist pins through the pipes on the side of the connecting rods.

The passages in the crossheads pass the oil from the wrist pins to the guides. After passing through the bearings the oil is collected in the base, where it settles and is used over again. The bearing caps must be set up tight and the main bearing liners must be close to the shaft; otherwise too much oil leakage will occur before reaching the last bearing. To prevent the entrance of foreign matter a strainer is attached to the suction valve of the pump. When the crank chamber is inspected, no waste, dirt or other matter must be allowed to enter and mix with the oil. When cleaning the oil chamber, *canvas* and *not* waste should be used, since the latter clogs the strainer.

Only mineral oil should be used for lubricating. An oil consisting of two-thirds red engine oil and one-third heavy cylinder oil has been found to give good results. Since the oil passes through the bearings repeatedly, it gradually loses its lubricating properties, becoming thick and gritty. It should, therefore, be occasionally run through a filter and mixed with new oil. The number of filterings required depends upon the oil as well as the length of time the engine operates.

The oil should stand about $2\frac{3}{4}$ in. above the suction and discharge valve, and no water should be allowed to mix with it. An oil pressure of about 15 lbs. should be maintained by regulating the adjusting screw of the relief valve.

Valves

In all single cylinder engines, the plain plug piston valve is employed without any expanding rings. These valves take steam through the inner edges, and exhaust past the outer edges. (On tandem compound engines the low pressure valves take steam through the outer edges and exhaust past the inner edges.) The travel of the valve is controlled by the automatic governor; varying the cut-off from $\frac{3}{4}$ to zero, depending upon the load. Great care is used in grinding and fitting these valves to their chambers, to obtain economical and satisfactory operation. The fit of these parts is most important.

Starting the Engines

Before steam is admitted to the cylinder see that the valve moves freely by turning the governor wheel by hand. As the expansion of the valve is much more rapid than the cylinder, the cylinder should be allowed to warm up before full pressure is applied. By allowing the set to come to full speed gradually, no trouble will be experienced due to the valve "seizing." The engineer in charge of the section always prepares the engines for test, including the adjustment of valves, governors, packing, taking of indicator diagrams, care of indicators, piping, condensers and apparatus for weighing water when water consumption tests are made.

Tests

Unless otherwise advised by the Engineering Notice covering the particular requisition and engine, all single cylinder commercial engines are tested for the following only:

      (1) Speed regulation.

      (2) Steam consumption.

(1) The steam and back pressures and electrical load are held constant. Then the speed variation is tested by suddenly putting on or throwing off load when the conditions are constant. The total variation between full and no load should not exceed $3\frac{1}{2}$ per cent. A speed regulation of 3 per cent. is usually obtained and at this value the stability of the governing mechanism is satisfactory. When adjustments are being made for speed regulation, duplicate readings on the generator must be obtained, and the voltage must be carefully noted to see if it is affected by fluctuations in engine speed. If any voltage fluctuation occurs, it must be reported to the engineer and the proper correction made. With the engine exhaust connected to the condenser the load must also be thrown on and off and the speed noted, especially at no load, to see that the valve completely shuts off steam and that the engine does not "run away" or "race."

(2) The performance of every engine must lie within the limits given in the tables furnished the Testing Department regarding steam consumption; the method of weighing the condensed steam being exactly the same as employed on the turbine test. The piping in the testing stand and valves is arranged so that the exhaust steam from the engine can be passed either to atmosphere or to the condensers. If the steam consumption is excessive, the piston should be examined to see that the rings are free in the grooves and that they have a good and even bearing against the cylinder walls. If the rings are in good condition the valve is probably too small in diameter and allows steam to blow directly into the exhaust. In bad cases there will generally be a considerable variation in speed as the governor cannot control the speed, with leaking valves.

Poor steam economy is generally due to the above causes, but lack of lubrication in the steam spaces, excessive friction

in the stuffing boxes and bearings, or poor valve setting will increase the amount of steam used.

Operation

During the operation of the set in test the following points should be carefully noted:

(1) Trueness of governor pulley.

(2) Concentricity of crank shaft with armature coupling and commutator.
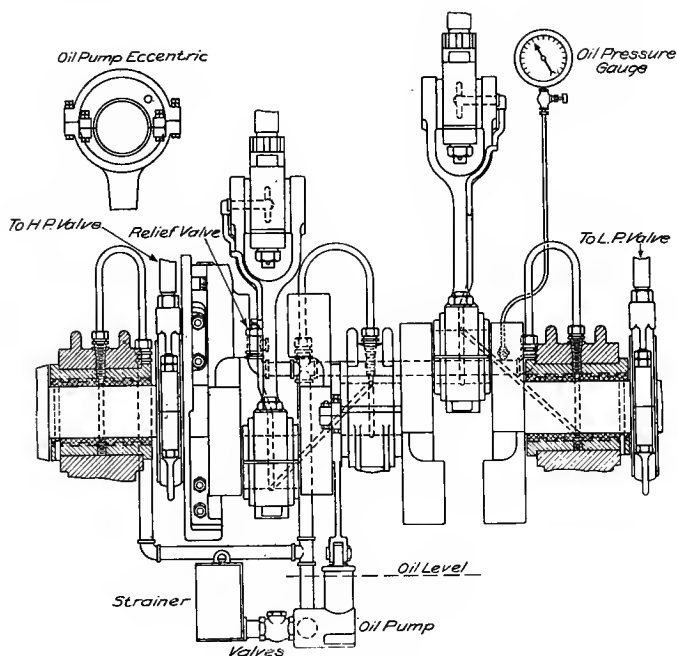
Fig. 184
LUBRICATING MECHANISM

(3) Absence of oil and grease throwing.

(4) Operation of engine in reference to quiet running.

(5) Proper alignment of all parts, especially the crank pin and wrist pin boxes, and central position of piston with reference to the cylinder, clearance of oil deflector of armature shaft from outboard bearing.

(6) Oil leakage around ends and at unions of Multiple Oiler, and at points where supply pipes pass through column on
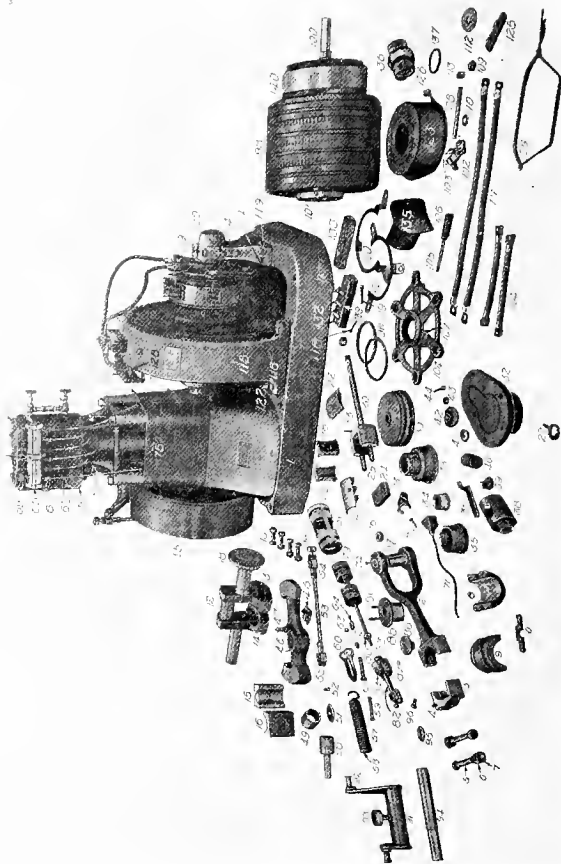
Fig. 185
PARTS OF GENERAL ELECTRIC COMPANY'S MARINE GENERATING SET

1 Base
2 Connecting rod with wrist pin
3 Cap
4 Cap set screw
5 Bolts
6 Nuts
7 Cotter pins
8 Crank pin brasses (top half)
9 Crank pin brasses (bottom half)
10 Liners
11 Column bolts and nuts
12 Crankshaft
13 Counterbalance (right)
14 Counterbalance (left)
15 Crankshaft bearing (top half)
16 Crankshaft bearing (bottom half)
17 Cap
18 Half coupling
19 Bolts and nuts
20 Crosshead and piston rod
21 Nut for piston rod
22 Shoes
23 Screws
24 Cap
25 Bolts
26 Nuts
27 Eye bolt
28 Wrist pin brasses (top half)
29 Wrist pin brasses (bottom half)
30 Cylinder
31 Drain valves
32 Head (top)
33 Head (bottom)
34 Gland
35 Brass nut
36 Spanner wrench
37 Studs and nuts
38 Relief valve casing
39   "   "   valve
40   "   "   spring
41   "   "   cap
42   "   "   cover
43   "   "   lock nut
44   "   "   adjusting screw
45 Governor pulley
46 Weight
47 Eccentric pin
48 Grease cup (automatic)
49 Bushing
50 Bearing pin
51 Cap
52 Securing screw
53 Governor connecting rod
54 Brasses (top)
55 Brasses (bottom)
56 Grease cup
57 Governor spring
58 Screwed plug
59 Adjusting screw
60 Shackle
61 Shackle bolt
62 Shackle nut
63 Shackle bushings
64 Shackle washers
65 Oil tank
66 End glass with washer
67 Sight feed glass
68 Distribution pipes
69 Filling plug
70 Bracket with screw
71 Oil cup and pipe for crank pin bearing
72 Oil cup securing screws for above
73 Oil cup with pipe for wrist pin bearing
74 Oil cup securing screws for above
75 Oil shield (front)
76 Oil shield (back)
77 Oil shield (generator side)
78 Oil shield (pulley side)
79 Piston valve
80 Stem with nuts
81 Bushing
82 Link
83 Link saddle
84 Link saddle pin
85 Valve stem stuff-box
86 Studs
87 Nuts
88 Gland
89 Piston
90 Rings
91 Rocker arm
92 Pins
93 Grease cup
94 Shaft
95 Cap
96 Securing screw
97 Wrist pin
98 Armature
99 Coil
100 Shaft
101 Half coupling
102 Brush-holder
103 Spring
104 Yoke
105 Binding spindle
106 Handle
107 Studs and nuts
108 Studs
109 Nuts
110 Washers
111 Cables
112 Insulating washers
113 Insulating bushings
114 Bolt for pole block
115 Bolt for pole piece
116 Bolt for magnet frame foot
117 Bolt for cable terminals
118 Bolt and washer for connection board
119 Dowel pin for pillow block
120 Bus ring (large offset)
121 Bus ring (small offset)
122 Dowel pin for magnet frame
123 Field coil
124 Series field cables
125 Shunt field terminal board
126 Washers, bolts and nuts for series coil
127 German silver shunt for series field
128 Support
129 Top bolt for O.B.B. cap
130 Gauge glass for O.B.B.
131 Magnet frame
132 Connection board
133 Support
134 Pillow block
135 Pole piece
136 Self-oiling sleeve
137 Rings for self-oiling sleeve
138 Soft rubber washers
139 Cable terminals
140 Commutator

gravity lubrication engine ; that the oil drips from supply pipes into proper oil cups and channels, and in engines oiled under pressure, the quiet operation of oil pump, and of the relief valve and pressure gauge in the system; the proper return of the oil lifted out by pump plungers ($1\frac{1}{4}$ in. holes are drilled around plunger support and in the pump cover for the return of this oil to the chamber).

(7) The operation and "hang" of throttle valve and alignment of handwheel in reference to the valve stem in engines having the valve bolted to the cylinder.

(8) Absence of leakage in cylinder casting, due to porous metal or other causes.

(9) Fit of oil shields.

(10) Tightness and adjustment of cylinder relief valves. These should be allowed to open at the proper pressure, then tighten the set screw in casing about one turn.

(11) Vibration.

(12) General appearance of entire set.
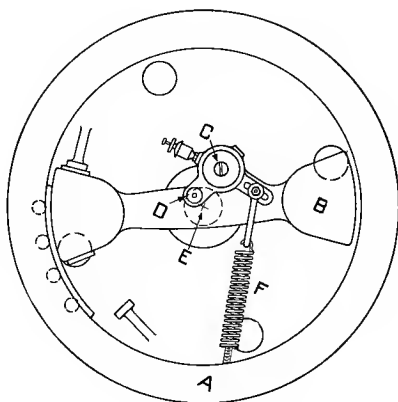
Fig. 186
GOVERNOR

Governor

The governor is simpler than the various flywheel governors using shifting eccentrics. It consists of a heavy flywheel A, keyed to the shaft and carrying the governor weight B, pivoted at C, and containing the eccentric pin D, which operates the valve. (See Fig. 186.)

The governor connecting rod, Part 53, Fig. 185, transmits motion from the governor to the valve, and is connected to

eccentric pin D. The length of the valve stroke, therefore, depends upon the distance of D from the centre of E. The amount of steam admitted to the cylinder varies directly as the distance between the centres of D and E.

If the engine speed increases, then the weight B is moved by centrifugal force toward the perimeter A, decreasing the distance of D from the centre of E and reducing the amount of steam admitted to the cylinder. If the speed of the engine becomes excessive, the distance of D from E is reduced to the minimum and the steam is entirely cut off.

The motion of the fly-weight B is opposed by the spring F, which is attached to the pulley and fly-weight. By increasing or decreasing the tension of the spring, the speed may be raised or lowered. The same effect will be produced by moving the spring in the slot of the weight, moving it away from the fulcrum increases the speed, and *vice versa*.

Unstable regulation is due to too close an adjustment of speed, and may be avoided by moving the speed attachment away from the fulcrum. A leaking valve or insufficient lubrication of the fly-weight fulcrum will also produce the same effect. If the lubrication is not sufficient the governor should be taken apart and cleaned. Only the best of soft grease should be used in the cup, and the governor should occasionally be taken apart and cleaned to obtain the best results.

The governors of some of the forced lubrication engines are enclosed by the engine column, and the bearing pin is lubricated by oil under pressure from the oiling system as shown in Fig. 184.

Packing

In all single cylinder engines, up to and including the 30 kw. size, the Garlock Spiral Packing is used in both piston rod and valve stem stuffing boxes, and in the valve stem stuffing boxes of all engines; the leakage being taken up by tightening the brass nut on the box.

In the piston rod stuffing boxes of the tandem compound, cross compound and of the single cylinder 50 kw. engine, United States Metallic packing is used. Fig. 187 shows the "Double" type which is commonly used, but in some machines the "Single Junior" packing is employed. The general construction of the two packings is similar.

The packings consist of vibrating cups A and A, receiving the packing rings 1, 2 and 3. These rings are in halves and, in assembling the packing, see that the joints are broken. The vibrating cups rest upon rings B and B, which have a spherical bearing, so that the packings will follow the rod in any position. The steam pressure forces the packing down in the cups and against the piston rod, thereby preventing steam leakage. The coil springs C and C assist this pressure, at the same time holding the packing in place and preventing the rings from following the rod at the moment of reversal. If the packing has been taken out for examination, the ground surfaces should be cleaned

and freed from grit before reassembling. The box holding the packing is drilled and tapped for a ⅛ in. waste pipe and fitted with a globe valve which should be always open.

Indicator Diagrams

When indicator diagrams are required, a stud is screwed into the wrist pin of the connecting rod for driving the motion, con-
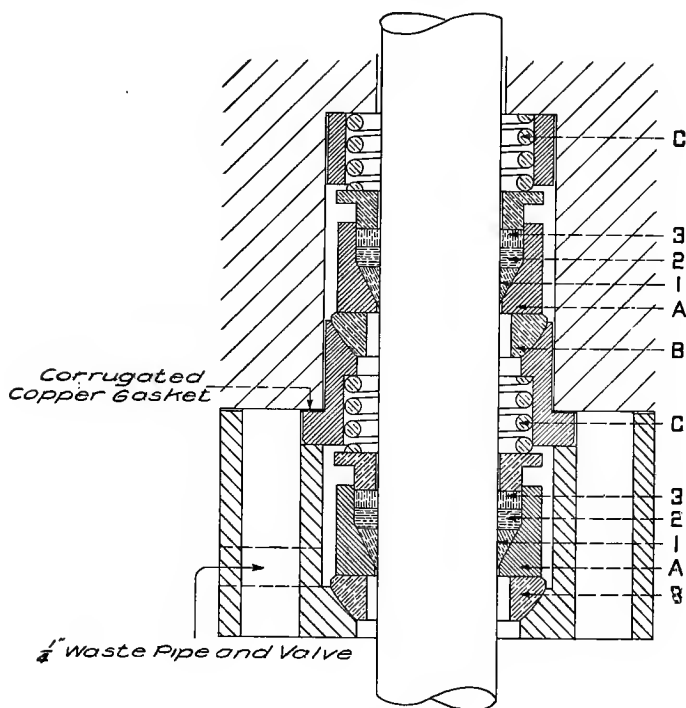
Fig. 187
PISTON ROD PACKING

necting through a link to a lever pivoted to the bracket on the engine column. The motion for the indicator is taken from a cord pin on this lever.

The indicator is a delicate instrument, and must be handled with care and kept in good order. The piston springs should be

frequently calibrated. Before attaching the indicator to an engine, blow steam freely through the pipes and three-way cock to remove any particles of dust or grit that may have accumulated in them. After using the indicator it should be carefully wiped and oiled. If any grit or other obstruction gets into the cylinder of the indicator the diagrams will give wrong results. This trouble is easily detected and should be remedied at once by taking out the piston, detaching it and cleaning with naphtha or benzine. Then carefully oil it with clean watch oil and replace. The piston must move perfectly freely in its cylinder. To test this take out piston and spring, detach the latter and replace the piston and piston-rod in their operating position, then, holding the indicator in an upright position, raise the pencil arm to its highest point and let it drop. It should freely descend to its lowest point.

Before taking diagrams, steam should be admitted to the indicator, and the cylinder allowed to become thoroughly heated. Indicator springs are made in different sizes of steel wire, to adapt them to different steam pressures. Springs are usually made to the following scales: 8, 12, 16, 20, 30, 40, 60, 80, and 100 pounds per inch travel of the indicator pencil. This scale is stamped on the spring. The spring used for indicating an engine depends upon the maximum steam pressure used; a spring should be chosen to give a diagram with maximum height not exceeding $1\frac{3}{4}$ in. The diagram should not exceed $2\frac{1}{2}$ in. to 3 in. in length. The less the vertical and horizontal motions are the slower the movement of the paper cylinder with a correspondingly more delicate pencil tracing. The proper spring required may be found as follows: Divide the boiler pressure, expressed in pounds, by the desired height of the diagram, expressed in inches, and the result will be the spring required. For instance, with a boiler pressure of 140 pounds gauge and a diagram height of $1\frac{3}{4}$ in., then $140 \div 1\frac{3}{4} = 80$, is the number of the spring required.

If too weak an indicator spring is used it will vibrate inside the indicator cylinder at admission and cause a wavy line on the card, hence the strength of the spring should be chosen with due regard to this point. The indicator cord should have sufficient tension on it to prevent any whipping action occurring at the extreme point of the stroke. Hence sufficient tension must be given to the rotary spring in the indicator to prevent this action. If the tension on this spring is not sufficient, the length of the indicator cards will vary; the higher the speed of the engine the greater will the variation be.

The pressure of the pencil on the paper can be adjusted by screwing the handle in and out. The line should not be heavy as this will cause unnecessary friction. After the diagram has been taken close the cock and take the atmospheric line; then disconnect the cord to avoid excessive wear on the drum.

The following notes should be made on the card and any other data which it is proper to add:

Date	Time	
Requisition No.		Dia. of rod
Kw. capacity		Cylinder
Card No.		Boiler pressure
Stroke		Exhaust pressure
Clearance		Revolutions per min.
Scale of spring		Volts
Engine No.		Amperes
Cylinder No.		Pounds of water per kw. hr.
Dia. cylinder		

A trifle more lead at the crank end of the valve should be given at no load, as at three-quarters or full load the average pressure on either side of the piston will be found to be practically equal, due to the angularity of the connecting rod. Various adjustments will be necessary to obtain the best diagram and operation of the engine.

General

An engine unit should not be considered mechanically nor electrically perfect, until the tests have so proved. Testers should familiarize themselves with every detail of design and operation, thereby helping towards the production of the most reliable piece of apparatus. After the inspection in the Engine and Testing Department the unit is disassembled in the engine section of the Shipping Department and thoroughly overhauled, touched up and re-inspected, preparatory to final shipment.

CALCULATION SHEETS

The following calculations, which have been made with the slide rule, are intended to illustrate the method used in connection with testing work. Every effort is made to avoid error but this Company does not guarantee their correctness nor does it hold itself responsible for any errors or omissions in these sheets.

SATURATION ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE 3-PHASE GENERATOR

Volts Arm.	Volts Field	Amps. Field	Speed R.P.M.
192	25	18.0	360
228	29	21.0	360
253	32	23.2	360
304	38	29.0	360
416	52	40.0	360
495	62	48.9	360
542	70	55.1	360
579	75	59.8	360
597 597 597	79	62.0	360
614	83	65.4	360
707	110	87.5	360
785	146	117.0	360
755	130	102.0	360
555	74	55.5	360
453	57	43.6	360
287	35	26.3	360
178	26	16.1	360

CALCULATION SHEET NO. 1

OPEN CIRCUIT CORE LOSS ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE 3-PHASE GENERATOR

		DRIVING MOTOR								GENERATOR		
	Volts Arm.	Amps. Arm.	Amps. Field	Speed R.P.M.	I.E. Input	I²R	I.E. −I²R	Core Loss	Volts Arm.	Volts Field	Amps. Field	Speed R.P.M.
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.2	62.0	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.0	85.0	2.5	500	9700	55	9645	1060	152	20.0	13.9	360
	114.2	90.0	2.5	500	10280	62	10218	1633	204	25.8	18.7	360
	114.3	95.5	2.5	500	10900	70	10830	2245	262	32.2	24.0	360
	114.5	103.0	2.5	500	11800	82	11718	3133	322	38.8	29.6	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.5	112.0	2.5	500	12820	96	12724	4139	386	46.9	36.4	360
	114.6	126.0	2.5	500	14420	122	14298	5713	453	54.6	42.6	360
	115.0	145.0	2.5	500	16700	162	16538	7953	515	63.7	50.2	360
	115.4	160.0	2.5	500	18450	200	18250	9665	562	71.2	56.2	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	115.5	166.0	2.5	500	19200	212	18988	10403	570	74.0	58.0	360
	115.8	173.0	2.5	500	20000	230	19770	11185	594	78.0	61.0	360
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.5	62.0	360
	116.5	185.0	2.5	500	21580	263	21317	12732	624	84.6	65.7	360
	116.8	212.0	2.5	500	24800	345	24455	15870	684	100.5	78.4	360
	117.0	238.0	2.5	500	27850	435	27415	18830	721	117.5	90.9	360
Motor Running Light	113.0	15.4	2.5	500	1745	1.82	1738	6847	Frictio n	and	Windage	

Driving Motor MP-4-60-550-125 V.   Res. Hot. = .0077 Ohms.

CALCULATION SHEET NO. 2

396

SHORT CIRCUIT CORE LOSS ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE 3-PHASE A.C. GENERATOR

| | DRIVING MOTOR | | | | | Core Loss + Gen. I²R | GENERATOR | | | | Speed R.P.M. |
	Volts Arm.	Amps. Arm.	Amps. Field	I.E. Input	I²R	I.E. − I²R		I²R	Core Loss	Amps. Arm.	Amps. Field	
Friction	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.0	93.0	2.5	10600	66	10535	1950	1320	630	236	12.4	360
	113.8	94.0	2.5	10710	68	10640	2055	1680	375	266	14.0	360
	113.5	106.0	2.5	12050	86	11965	3380	2540	840	328	18.0	360
	114.2	115.0	2.5	13130	102	13030	4445	3440	1005	382	19.8	360
	115.0	125.0	2.5	14380	120	14260	5675	4130	1545	418	21.6	360
Friction	113.5	76.0	2.5	8630	−45	8585	0	0	0	0	0	360
	114.2	130.0	2.5	14850	130	14720	6135	4540	1595	438	22.6	360
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
	115.2	158.0	2.5	18200	192	18010	9425	6780	2645	536	27.6	360
	114.2	176.0	2.5	20100	238	19860	11275	8350	2925	594	30.6	360
	115	204.0	2.5	23450	320	23130	14545	10400	4145	662	34.0	360
	116	232.5	2.5	27000	415	26585	18000	12700	5300	732	37.5	360

Driving Motor MP 4-60-550-125 V.   Res. Hot = .0077.   Generator Res. Bet. Lines including
leads to table = .0158 Av. of resistance before and after test.

CALCULATION SHEET NO. 3

397

CALCULATIONS OF DECELERATION CORE LOSS ON A 3000 KW., 2300 V., 10-POLE, 60 CYCLE, 3-PHASE GENERATOR

. Moment of Inertia is equal to $705,000 = Wr^2$.

The normal speed of the turbine being 720, S_1 is taken equal to 730 and S_2 equal to 710.

Consider curve taken with no field on the machine. (See Fig. 37.)

T_1 or time corresponding to $S_1 = 61.6$ seconds.

T_2 or time corresponding to $S_2 = 82.4$ seconds.

$T_2 - T_1 = 82.4 - 61.6 = 20.8$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{T_2 - T_1} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1 + S_2)(S_1 - S_2)}{T_2 - T_1}$$
$$= \frac{2308}{10^{10}} \times \frac{705000 \times 28800}{T_2 - T_1} = \frac{4700}{T_2 - T_1}$$

Substituting the value of $T_2 - T_1$ in the formula

Kw. Loss $= \dfrac{4700}{20.8} = 226 =$ Friction and Windage

For the curve taken with 77.4 amperes field current
$T_2 - T_1 = 70.6 - 52.1 = 18.5$

Kw. $= \dfrac{4700}{18.5} = 254 =$ Core loss + Friction + Windage.

Curves taken with 103,129 and 142 amperes field are calculated similarly, and together with that taken at 77.4 ampere-field include the constant friction loss and core loss. The two losses can be separated.

Amps. Field Held	T_1	T_2	$T_2 - T_1$	S_1	S_2	$S_1^2 - S_2^2$	Friction	Core Loss and Friction	Core Loss	Volts from Saturation
0	61.6	82.4	20.8	730	710	28000	226	226	0	0
77.4	52.1	70.6	18.5	730	710	28000	226	254	28	1570
103	48.2	66.1	17.9	730	710	28000	226	266	40	1990
129	44.4	60.5	16.1	730	710	28000	226	292	66	2350
142	42.8	58.2	15.4	730	710	28000	226	306	80	2500

From the saturation curve the volts armature corresponding to the various field currents used can be obtained and a core loss curve plotted between volts armature as abscissæ and core loss as ordinates.

S_1 and S_2 are usually assumed at 2 per cent. above and 2 per cent. below normal speed.

CALCULATION SHEET NO. 4

FIELD COMPOUNDING ON A 150 KW., 250 V., 6-POLE, 225 R.P.M., D.C. GENERATOR

6 BARS BRUSH SHIFT

Volts Arm.	Amps. Arm.	Volts Field	Amps. Field	R.P.M.
250	0	226	10.8	225
250	150	240	11.65	225
250	300	270	12.90	225
250	450	300	14.3	225
250	600	334	15.9	225
250	750	370	17.6	225

CALCULATION SHEET NO. 5

PHASE CHARACTERISTICS ON A 300 KW., 600 V., 750 R.P.M., 25 CYCLE 3-PHASE ROTARY CONVERTER

NO LOAD					FULL LOAD 500 AMPS. D.C.				
Volts D.C.	Volts A.C.	Amps. A.C.	Amps. Field	Volts Field	Volts D.C.	Volts A.C.	Amps. A.C.	Amps. Field	Volts Field
600	378	315	.75	91	600	384	601	1.05	125
600	377	255	1.25	150	600	383.5	570	1.25	150
600	376	210	1.50	180	600	381	543	1.50	180
600	375	156	1.75	210	600	380	520	2.00	240
600	374	120	2.00	240	600	379	512	2.25	270
600	373	85	2.20	265	600	378	507	2.50	300
600	373	65	2.30	275	600	378	505	2.65	320
600	372	41	2.40	290	600	378	510	2.75	330
600	371	23	2.50	300	600	376	525	3.00	360
600	370	14	2.55	305	600	375	547	3.50	420
600	370	17	2.60	315	600	374	585	4.00	485
600	369	21	2.65	320	600	373	627	4.50	540
600	369	35	2.75	332	600	370	685	5.00	600
600	369	75	3.00	360					
600	368	116	3.25	395					
600	367	170	3.50	420					
600	366	205	3.75	450					

CALCULATION SHEET NO. 6

SYNCHRONOUS IMPEDANCE ON A 500 KW., 600 V., 20-POLE 60 CYCLE 3-PHASE GENERATOR

Amps. Arm.	Volts Field	Amps. Field	Speed R.P.M.
224	15.0	11.9	360
260	17.8	13.7	360
300	20.6	15.8	360
352	23.8	18.3	360
398	26.9	20.7	360
474	31.5	24.5	360
480 480 } 480	32.2	24.8	360
518	34.8	26.7	360
557	37.5	28.2	360
704	47.0	36.1	360
796	52.8	40.6	360
896	59.5	45.7	360
1000	66.5	51.1	360

CALCULATION SHEET NO. 7

EFF. AND LOSSES OF A 100 KW., 525/575 V., COMP. WOUND, 6-POLE, 275 R.P.M., D.C. GEN.

	0	25	50	75	100	125	150
% Load	0	25	50	75	100	125	150
Volts Line	525	537.5	550	562.5	575	575	
Amps. Line	0	43.5	87.0	130.5	174	217.5	
Amps. Shunt Field	3.10	3.18	3.25	3.32	3.40	3.4	
Amps. Armature	3.1	46.7	90.3	133.8	177.4	220.9	
Amps. Series Field	0	29.2	58.4	87.6	116.8	146	
Amps. Series G. S. S.	0	14.3	28.6	42.9	57.2	71.5	
IR Drop	.417	.628	12.15	18.0	23.9	29.7	
E + IR	525.4	543.8	562.2	580.5	598.9	604.7	—
Core Loss	1042	1124	1205	1295	1395	1425	
Brush Friction	314	314	314	314	314	314	
Bearing Friction							
I^2R Armature	—	213	797	1750	3080	4770	
I^2R Brushes	—	36	117	222	331	445	
I^2R Shunt Field	1630	1710	1790	1870	1950	1950	
I^2R Rheostat	0	33	131	296	523	820	
I^2R Series Field	0	16	64	144	257	403	
I^2R G. S. S.						125	
Total Losses	2986	3.446	4418	5891	7850	10127	
Kw. Output	0	23.4	47.8	73.4	100	125	
Kw. Input	2.99	26.85	52.24	79.29	107.85	135.1	
% Efficiency	0	87.2	91.5	92.6	92.7	92.6	
Brush Density		8.3	16.05	23.8	31.6	39.3	
Brush Contact Res.		.01665	.0144	.01244	.01055	.0091	

Resistance of Armature 25° C. .0893 Ohms, Warm .098 Ohms at 51° C.
Resistance of Shunt Field 25° C. 97.4 Ohms, Warm 105.3 Ohms at 47° C.
Resistance of Series Field 25° C. .0358 Ohms, Warm .0386 Ohms at 46° C.
Resistance of Series G. S. S. .079 Ohms.
Dimensions of Brushes 1¼"×¾". No. of Studs 6. No. per Stud 4. Coeff. of Friction = .2.
Brush Contact Area, One Side 5.625 Sq. In. Brush Pressure 1¼ Lbs. per Brush.

CALCULATION SHEET NO. 8

EFFICIENCY AND LOSSES OF A 70 H.P., 500 V., 6-POLE, 850 R.P.M., D.C. MOTOR

Volts Line	500	500	500	500	500
Amperes Line	29	58	87	116	145
Amperes Field	2.43	2.43	2.43	2.43	2.43
Amperes Arm.	26.5	55.5	84.5	113.5	142.5
IR	3	6	9	12	15
E—IR	497	494	491	488	485
Speed					
Core Loss.	2500	2475	2450	2400	2350
Brush Friction	460	460	460	460	460
Bearing Friction	530	530	530	530	530
I²R Armature.	63	275	638	1150	1820
I²R Brush	12	50	105	172	243
IE Field	1215	1215	1215	1215	1215
Total Losses	4780	5005	5398	5927	6618
Kw. Input	14.5	29.0	43.5	58.0	72.5
Kw. Output	9.72	24	38.1	52.07	65.88
H.P. Output	13.02	32.1	51	69.7	88.3
% Efficiency	67.0	82.8	87.6	89.8	90.8
Brush Density	4.71	9.89	15	20.2	25.4
Brush Contact Resis.	.0178	.0162	.01476	.0133	.01195

Resistance of Armature 25° C. .0816 Ohms   Warm .0895 Ohms at 50° C.
Resistance of Field 25° C. 169 Ohms   Warm 191.5 Ohms at 60° C.
Dimensions of Brushes 1¼ in. × ½ in.   No. of Studs 6.   No. per Stud 3.   Pressure per Brush 1½ lbs.
Brush Contact Area, One Side 5.62 Sq. In.

CALCULATION SHEET NO. 9

INPUT OUTPUT OF A 100 H.P., 600 V. RAILWAY MOTOR

Motor

Volts	600	600	600	600	600
Amps.	60.5	94.0	134	178	249
R.P.M.	1216	935	790	700	610
Watts Input	36300	56400	80400	106800	149200
I^2R { Arm. + Brushes + Exc. Fld. + Comm. Field	935	2260	4590	8100	15800
(A) = Watts − (I^2R)	35365	54140	75810	98700	133400
(A) − (Core Loss + Fric.) = Output	29382	48180	69410	90755	123150
Efficiency	80.9	85.4	86.4	85.0	82.5

Generator

Volts	602	592	580	551	522
Amps.	385	70	105.5	142.5	203
Watts	23150	41400	61150	79400	106000
I^2R { Arm. + Brush + Comm. Field	248	820	1860	3410	6900
(B) { Watts + I^2R	23398	42220	63010	82810	112900
(A − B) ÷ 2 = Core Loss + Friction (1 Mach.)	.5983	5960	6400	7945	10250

Resistances

	Motor	Generator
Armature	.1082	.1015
Exciting Field	.0792	—
Comm. Field	.0522	.0492
Brush Contact	.0170	.0170
Total	.2566	.1677

CALCULATION SHEET NO. 10

SPEED, TRACTIVE EFFORT AND EFFICIENCY OF A 100 H.P. 600 V. RAILWAY MOTOR

INPUT		I^2R %	Core Loss %	Gear + Friction %	Effici- ency %	Miles per Hour on 33" Wheels Gear Ratio 3.35	Tractive Effort
Volts	Amps.						
600	40	1.7	5.3	30.0	63.0	45.0	170
600	60	2.5	4.1	14.0	79.4	35.4	407
600	80	3.3	3.4	9.0	84.3	29.6	687
600	100	4.2	3.0	7.5	85.3	26.2	984
600	120	5.0	2.6	6.5	85.9	23.8	1310
600	140	5.9	2.3	5.7	86.1	22.5	1615
600	160	6.7	2.1	5.0	86.2	21.3	1960
600	200	8.4	1.8	5.0	84.8	19.5	2630
600	240	10.0	1.5	5.0	83.5	18.1	3350
600	280	11.7	1.3	5.0	82.0	17.2	4040

Resistances at   75°C.
Armature   .107
Exciting Field   .   .076
Commutating Field   .   .   .050
Brush Contact   .   .   .017
   Total   .   .   .250

CALCULATION SHEET NO. 10A

EFF. AND LOSSES OF A 300 KW., 600 V., 4-POLE, 25 CYCLE 3-PHASE ROTARY CONVERTER

% Load	0	25	50	75	100	125	150
Volts Line	600	600	600	600	600	600	600
Amps. Line	0	125	250	375	500	625	750
Amps. Shunt Field	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Amps. Arm. D.C.	2.65	127.6	252.6	377.6	502.6	627.6	752.6
Amps. Arm. A.C.		120.2	238	356	474	592	710
Core Loss	4760	4760	4760	4760	4760	4760	4760
Brush Friction D.C.	1134	1134	1134	1134	1134	1134	1134
Bearing Friction	2654	2654	2654	2654	2654	2654	2654
I^2R Armature ($.59 \times$ D.C. I^2R)	0	269	1056	2340	4170	6500	9300
I^2R Brushes D.C.	0	101	340	641	960	1280	1720
I^2R Shunt Field	900	900	900	900	900	900	900
I^2R Rheostat	690	690	690	690	690	690	690
I^2R A.C. Brushes	211	18	70	156	276	431	555
I^2R A.C. Brush Fric.		211	211	211	211	211	211
Total Losses	10349	10737	11815	13486	15755	18560	21924
Kw. Output	—	75	150	225	300	375	450
Kw. Input	10.3	85.7	161.8	238.5	315.7	393.5	471.9
% Efficiency	0	87.4	92.7	94.3	95.0	95.3	95.4
Brush Den-sity { A.C.	—	8.85	19.5	29.2	38.9	48.5	58.2
Brush Den-sity { D.C.	—	8.5	16.9	25.2	33.6	41.9	50.2
Brush Contact Resis. { A.C.	—	.00123	.00123	.00123	.00123	.00123	.00123
Brush Contact Resis. { D.C.	—	.0062	.00534	.00451	.0038	.00326	.00304

Resistance of Armature D.C. End 25° C. .0243 Ohms, Warm .0280 Ohms at 65° C.
Resistance of Shunt Field 25° C. 111.3 Ohms, Warm 128. Ohms at 65° C.
Dimensions of Brushes { 1⅜×1⅞ arc of contact (A.C.) No. of Studs 4 D.C./12 A.C. No. per Stud 8 D.C./1 A.C.
{ ¾×1¼ (D.C.).
Brush Contact Area, One Side { 15 Sq. In. D.C. { 12.2 Sq. In. per ring(A.C.) Brush Pressure 2 Lbs. per Brush.
Coeff. of Friction = .2 D.C. Coeff. of Friction = .12 A.C.

CALCULATION SHEET NO. 11

EFF. AND LOSSES OF A 5000 KW., 11000 V., 28-POLE, 60 CYCLE 3-PHASE GENERATOR

% Load	0	25	50	75	100	125
Volts Line	11000	11000	11000	11000	11000	11000
Amps. Line	0	65.5	131	196.5	262	317
Amps. Fld.	220	224	228	235	245	257
IR	—	12	24	36	48	50
V+IR	11000	11012	11024	11036	11048	11050
Core Loss	143000	143000	143100	143600	144100	147000
¼ Short Cir. Core Loss	—	—	200	580	1300	2500
I²R Arm.	0	1330	5320	12000	21300	31100
I²R Fld.	14500	15000	15600	16600	18000	19800
Friction	25000	25000	25000	25000	25000	25000
Total Losses	182500	184330	189220	197700	209700	225400
Kw. Output	0	1250	2500	3750	5000	6250
Kw. Input	182.5	1434	2689	3948	5210	6475
% Efficiency	0	87.3	93.0	95.0	96.0	96.5

Res. Arm. (Line) .1927 Ohms 25° C. .207 Ohms Hot.
Res. Fld. .2795 Ohms 25° C. .3005 Ohms Hot.

CALCULATION SHEET NO. 12

EFF. AND LOSSES OF A 1070 H.P., 13200 V., 6-POLE, 25 CYCLE 3-PHASE SYN. MOTOR

% Load	0	25	50	75	100	125	150
Volts Line	13200	13200	13200	13200	13200	13200	13200
Amps. Line	—	9.5	19.0	28.5	38.0	47.5	57
Amps. Fld.	50.1	50.6	51.0	55.1	59.7	63.8	68.9
IR	—	34.5	69.0	103	168	172	205
(V − IR)	13200	13165	13131	13097	13032	13028	12995
Core Loss	13900	13800	13700	13600	13500	13400	13300
⅓ Short Cir. Core Loss	—	47	107	190	310	473	760
I²R Arm.	—	565	2265	5100	9040	14100	20400
I²R Fld.	3550	3630	3680	4300	5050	5770	6710
Friction	6272	6272	6272	6272	6272	6272	6272
Total Losses	23722	24314	26024	29462	34172	40015	47442
Kw. Input	23.72	220.63	436.68	654.3	871.05	1089.8	1306.7
Kw. Output	0	196.32	410.66	624.8	835.9	1049.8	1259.3
H.P. Output	0	263.2	550	837	1121	1408	1689
% Efficiency	0	89.0	94.1	95.5	96.1	96.3	96.4

Res. Arm. (Line) 3.86 Ohms 25° C. 4.18 Ohms Hot 47°C.
Res. Fld. 1.34 Ohms 25° C. 1.42 Ohms Hot 46°C.

STARTING TEST ON A 425 KW., 11000 V., 8-POLE, 25 CYCLE 3-PHASE, SYN. MOTOR

	VOLTS LINE			AMP. LINE			Ind. Volts per Spool	Pos. at Start	Time to Syn.
	1-2	2-3	1-3	1	2	3			
Rest .	1340	1430	1480	15	17.5	15.2	52	1	
Start.	2650	2650	2650	9.2	35	8.9	90.7		66 Sec.
Syn. .			2650		9				
Rest .	1255	1340	1340	15	16	13.6	47	2	
Start.	2560	2560	2560	9.5	30	9.2	88.3		70 Sec.
Syn. .		2560			9.3				
Rest .	1155	1300	1320	15	14	12.7	45	3	
Start.	2380	2380	2380	29.5	10.2	10	84.7		70 Sec.
Syn. .			2380	10					
Rest .	1248	1260	1165	15	12.8	13.8	44	4	
Start.	2590	2590	2590	33	9.3	9.5	80.8		68 Sec.
Syn. .		2590		9					
Rest .	1400	1308	1302	15	13.9	16.2	49	5	
Start.	2620	2620	2620	8.9	9.1	32	87		64 Sec.
Syn. .	2620					9.3			

Is there any tendency to stick at half speed? No.

CALCULATION SHEET NO. 14

EXCITATION ON A 100 H.P., 2080 V., 6-POLE, 60 CYCLE 3-PHASE INDUCTION MOTOR

Volts	Amps.	Watts +	Watts −	Total Watts
2510	11.5	18300	12150	6150
2370	10.4	15500	9900	5600
2175	9.5	12900	8000	4900
2105	9.2	12090	7380	4710
2075	8.8	11470	6920	4550
2020	8.6	10870	6370	4500
1830	7.7	9060	5060	4000
1610	6.76	6950	3450	3500
1440	6.03	5740	2670	3070
2160	15.4	5150	—	
2070	14.6	4750	—	
2000	14.2	4550	—	
2070	14.6	—	4950	
2200	15.85	—	5140	
2235	15.9	—	5540	
1366	5.78	5440	2310	3130
1185	5.08	4390	1540	2850
988	4.3	3185	685	2500
816	3.75	2550	178	2372
585	3.35	1670	+380	2050
485	3.25	1370	530	1900
292	3.9	1200	644	1844
244	4.85	1210	673	1883
176	5.8	974	500	1474

CALCULATION SHEET NO. 15

IMPEDANCE ON A 100 H.P., 2080 V., 6-POLE, 60 CYCLE 3-PHASE INDUCTION MOTOR

Volts	Amps.	Watts +	Watts −	Total Watts
146	11.9	1230	445	785
188	15	1870	660	1210
220	18	2825	1080	1745
263	21.5	4060	1485	2575
301	24	5260	1930	3330
355	28.5	7255	2845	4410
384	30.7	8360	3190	5170
410	33	9450	3710	5740
455	36	11680	4450	7230
297	20.6	—	1460	
272	19.1	—	1190	
322	22.2	—	1680	
273	19	1255	—	
297	20.5	1500	—	
322	22.2	1720	—	

CALCULATION SHEET NO. 16

STATIONARY TORQUE ON A 15 H.P., 220 V., 6-POLE, 60 CYCLE 2-PHASE INDUCTION MOTOR

Lever Arm.	Controller Pos.	Volts	Amp.	W+F	W−F	W+F+T	W−F+T	W	W+T	T	Norm. T 1 Ft.
2 ft. {	1	220	21–41	16.25	14.25	33	33	15.25	33	17.75	35.5
	2	220	36–39	17.25	14.25	50.75	48.75	15.75	49.75	34	68
	2	220	38–37	17.25	16.25	47.75	47.75	16.75	47.75	31	71
	3	220	57–34	17.25	16.25	54.75	53.75	16.75	54.25	37.5	86
2.292 ft. {	4	220	96–44	17.25	17.25	67	66	17.25	66.5	49.25	113
	4	220	98–45	17.25	17.25	68	66	17.25	67	49.75	114
	6	209	121–92	16.25	16.25	78	78	16.25	78	61.75	156
	7	187	195–97	17.25	16.25	61.75	59.75	16.75	60.75	44	139
	8	175	173–162	16.25	15.25	51.75	50.75	15.75	51.25	35.5	128.7

Lever Arm. = 2 ft. and 2.292 ft.
Normal running torque at 1 ft. radius = 65.6 lbs.

CALCULATION SHEET NO. 17

SUBJECT INDEX

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